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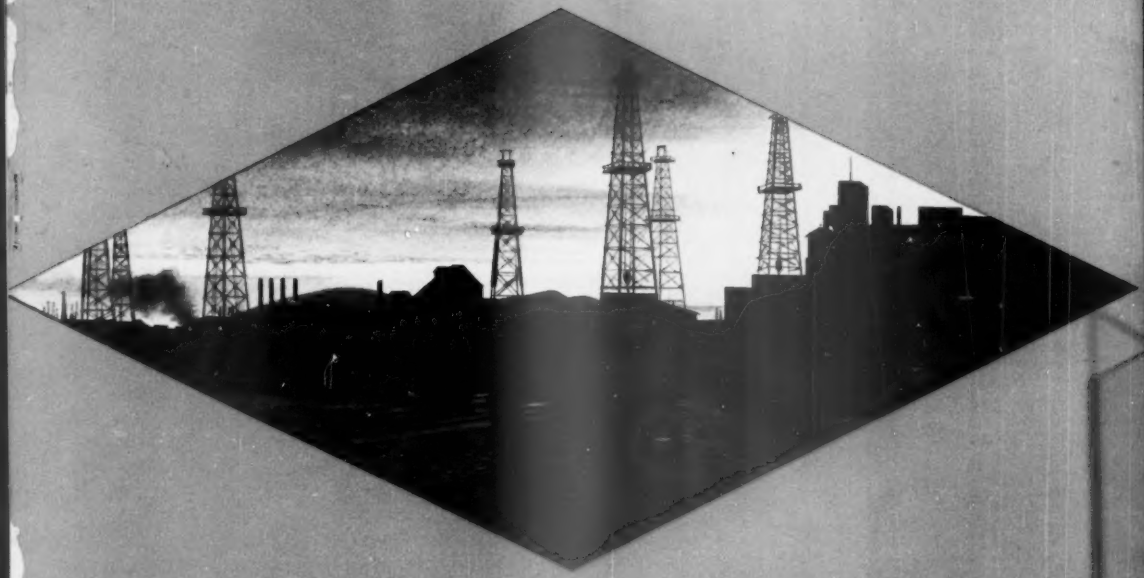

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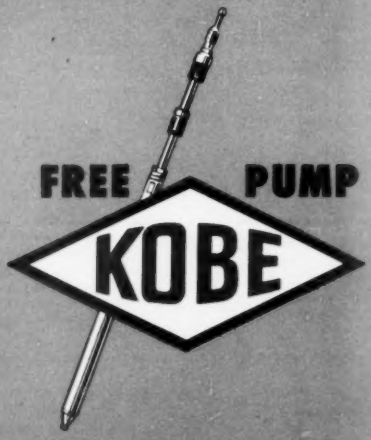

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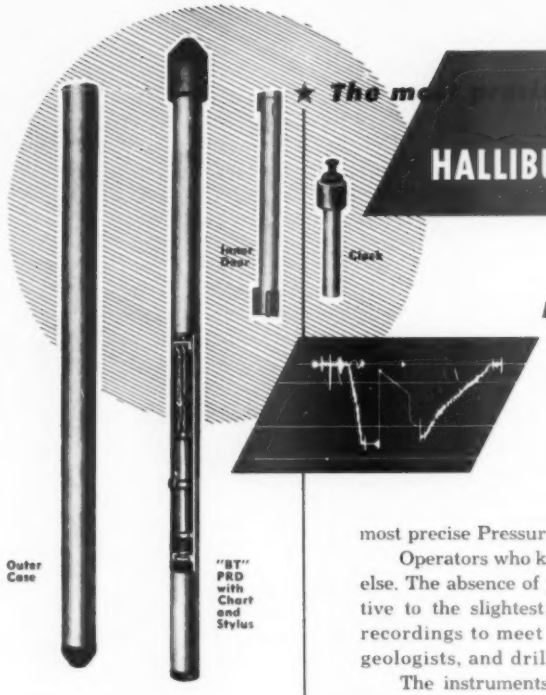

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PETROLEUM BRANCH
American Institute of Mining and Metallurgical Engineers, Inc.

408 Trinity Universal Building
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On the Cover — Among the innumerable individual operations that are necessary to the discovery and utilization of petroleum is the accurate and detailed mapping of fields. On our cover this month a surface map tracing is being made from an aerial photo. *Photo courtesy Pennsylvania State College.*

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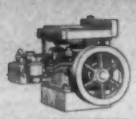
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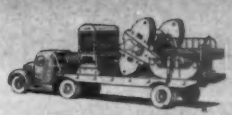
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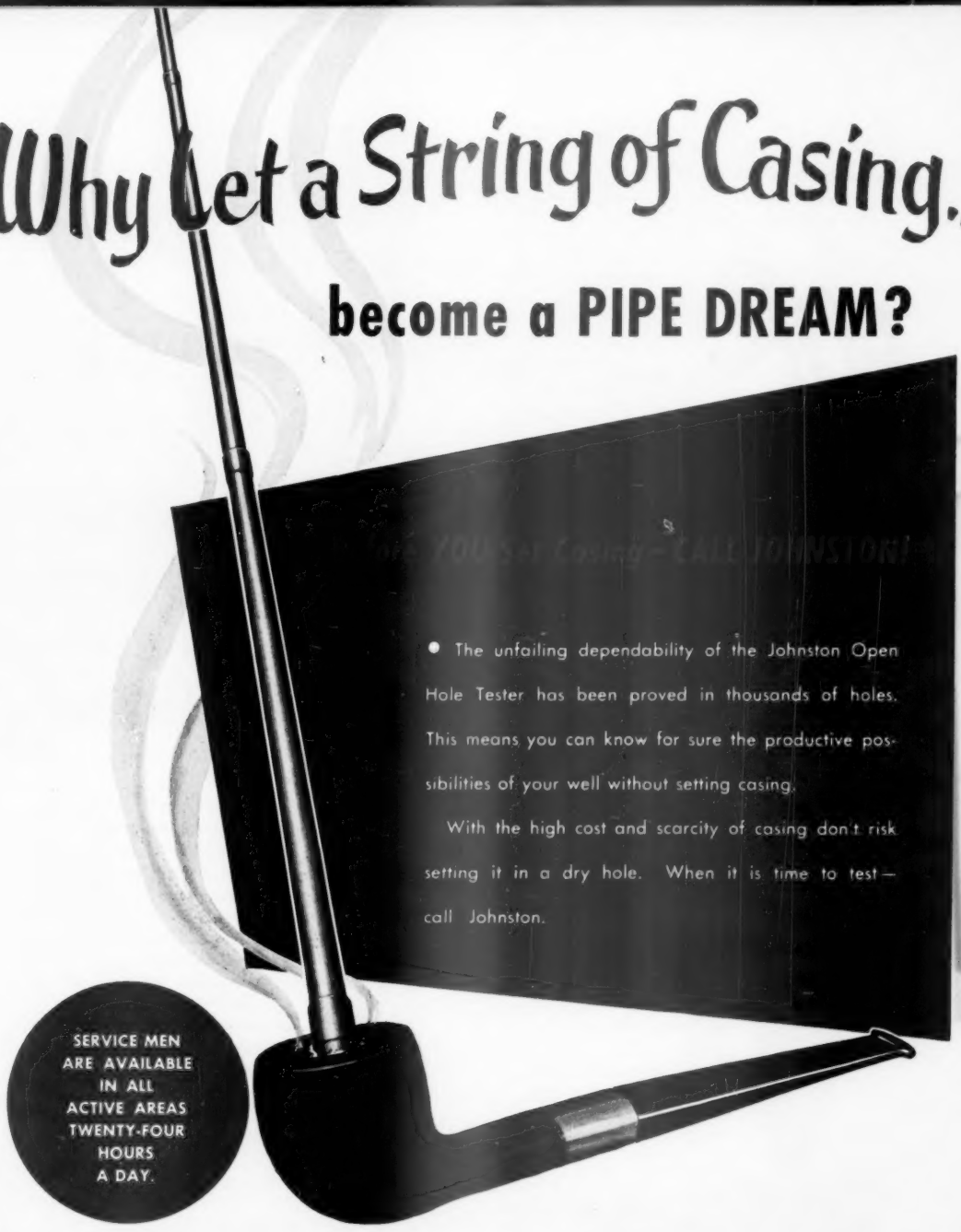

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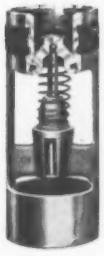

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Guest Editorial

Oil in a Free Economy

By John M. Lovejoy
President, Seaboard Oil Co.
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I HAVE been a member for the past year of the Oil Availability Committee of the National Petroleum Council. A great many people of the industry — geologists, economists and executives — have contributed their time to this study. The report of the Committee will soon be published. I want to quote the conclusion and then discuss the matter briefly. The conclusion is as follows: "In short, the United States and the world can count upon increasing supplies of oil and gas, not only for the next few years but for the foreseeable future provided that reasonable economic incentives, adequate materials, and a favorable climate for private investment prevail."

In view of the fact that this country has recently become a net importer of oil and its products, this conclusion may sound a bit too optimistic. Of course, the future *world* availability of oil does seem quite adequate, but we are more interested in keeping our own country self-sufficient. Demand for oil in the United States has been increasing so rapidly, I for one have wondered whether we could meet it, retaining at all times some surplus MER capacity in the event of emergency. The supporting data convince me that we can do so.

Firstly: Availability of oil or any other mineral resource is largely determined by economics. The present price of oil has provided the money to drill enough wells to add to our reserves and to our availability. Perhaps we will soon have to drill 50,000 wells a year instead of 44,000. Perhaps a higher price will be required in order to stimulate that much drilling. At any rate, up to now reserves and availability have always increased with increased drilling and the price of oil controls the rate of drilling.

Also, higher prices extend the life of marginal wells, accelerate secondary recovery projects and cause an infinite number of activities to increase production which could not be done at lower prices. In fact, economics largely determine the tempo of technological advancement.

Secondly, the vast areas of potential oil land in this country are most impressive. The axiomatic truth that with every oil field discovered one less remains to be found can be modified for the foreseeable future and restated to the effect that each new discovery provides the clues which lead to additional discoveries.

Of the 34 potential oil provinces listed in the AAPG symposium in 1941, only ten years ago, 25 have already proved to have production. Also, the 1951 symposium outlines 60 potential provinces against the 34 which geologists recognized ten years earlier.

What is it that makes possible the finding and development of so much oil in this country? In my opinion, it is *competition* in a free economy. When a new oil discovery is made, hundreds of companies and thousands of individuals go to work with incredible speed. Millions of acres are leased and the grueling, expensive task of evaluating the area with geologists, geophysicists and with the drill commences. Be it offshore 30 miles, in the swamplands of Louisiana, in the reaches of West Texas, the plains of Nebraska, the barren Dakotas, picturesque Wyoming, Montana and Utah, the frozen muskeg of Alberta, or the orange groves of California, you will find the same intensive competition. The great integrated companies generally are found in every new area for the simple reason that they can't afford not to be well represented if the area should prove to be important. The smaller units and individuals are there in hopes that it may be easier to find oil there than some other area where they may have just drilled a lot of dry holes. The old adage that far-away pastures look greener certainly applies to the oil man — and that's why we are going to find lots more oil.

If, at some distant future date, we are really faced with the problem of limited oil supplies, economics and competition will force many changes to again bring about a balance of supply and demand. It is through such adjustments that a free economy provides users with the best and cheapest form of fuel available at any period of time. ★ ★ ★

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ONE HOUR 45 MINUTES	String Shot	Backed-off tool joint at 6500 feet
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TWO HOURS 20 MINUTES	Type "B" Bridging Plug and running Feeler	Set plug at 6400 feet
THREE HOURS 45 MINUTES	Glass Jet Perforator	126 holes shot at 3600 feet (greatest depth)
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Pressure Control by Water Injection — A Resume of Case Histories

By E. P. Burtchaell* and E. R. Smith**

ABSTRACT

Case histories of 11 fields in the Mid-Continent area, visited in early 1951, where water is used as a primary pressure control medium are presented. Where available, detailed information on reservoir fluid and sand characteristics, water treatment, surface and subsurface equipment, degree and methods of reducing or eliminating by-passing of injected water, operating and injection costs and magnitude of benefits achieved and/or indicated, are included.

INTRODUCTION

In order to study and evaluate the use of water as a pressure control medium, the authors early in 1951 made a tour of primary water flood projects in operation in the Mid-Continent area of the United States. Projects visited were Porter and New Hope in Texas; East and West Hackberry, Longville, Mamou, in Southern Louisiana; Haynesville in Northern Louisiana; and Magnolia, Midway, Schuler and Wesson in Southern Arkansas. Fig. 1 illustrates the geographic location of the fields.

Specifically, detailed information was sought on reservoir characteristics of the pools, methods of water treatment, types of both surface and sub-surface injection equipment used, degree and methods of reducing or eliminating by-passing of injected water, operating and injection costs, and magnitude of benefits currently indicated.

*Honolulu Oil Corp.
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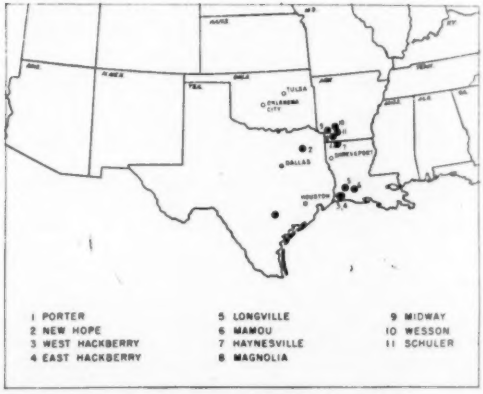

FIG. 1 — GEOGRAPHIC LOCATION OF FIELDS.

SUMMARY OF FIELDS

In Table I are presented pertinent data regarding the geology, physical and chemical properties and performance statistics of the various projects.

Porter

The Pettus Sand of the Porter Field is characterized by being a dirty, Bentonitic sand. Field experience has demonstrated that it is sometimes impossible to bring a well back on production after it has been killed with fresh water. Due to excessive gas production, at the start of unitization there was only one unpenalized well in the field. The pressure decline in the pool was arrested immediately after the start of water injection. Current producing wells produce oil with a low gas/oil ratio. Direct results of water injection have been the return to low gas/oil ratio production of three updip wells. There has been no indication of water channeling to date.

New Hope, Bacon Lime Pool

Water injection has resulted in a substantial reduction in well operating costs. At the start of the injection program all wells in the pool were on the pump. As of Jan. 1, 1951, some 23 wells were flowing and only six were pumping. No channeling of the injected water has yet been observed. The ability to control water is evidenced by the following example: In the east end of the pool, water was injected into Minshew No. 1 at rates as high as 2,000 B/D. Eventually the Young, Sanders, and Clark wells to the northwest were flooded to an 80 per cent cut without evidence of channeling. The injection rate into Minshew No. 1 was reduced to 300 B/D and injection into Alexander No. 3, injection well to the northwest, pushed the oil back across these producing wells with the result that the cuts were reduced. In fact, one well began flowing pipe line oil.

Hill Sand Pool

Purpose of operation of the Hill Sand flood is to increase the reservoir pressure to the initial value and flow wells to depletion at a faster rate. These wells are annulus completions and as this reservoir contains the smallest reserves of the three zones, it is hoped that the pool can be depleted in five to six years, thereby leaving only the Bacon and the Pittsburg Zones to contend with.

Pittsburg Sand Pool

The Pittsburg Sand is a very dirty sand containing large amounts of Bentonite. Due to the tightness of the sand, high injection pressures are necessary. Fresh water is being injected into the pool mainly because the surface equipment stands up better under high pressure fresh water injection. Salt water injected under high pressures caused considerable trouble with the fluid ends of the pump. Even though the sand possesses a high Bentonitic content there has been no trouble experienced with plugging of the injection wells.

East Hackberry

Due to lack of an adequate gas supply and location and depth of producing wells on the structure, water injection was started in order to maintain flow conditions and recover oil located in interval between oil-water contact and bottom of producing wells.

The flood front has moved uniformly updip with the lowest structure wells cutting first. The first well to show a cut was located the farthest away from the injection well but was the lowest producing well on the structure. The reservoir pressure has leveled off and varies directly with the water input rate.

The future plan of operation of this reservoir is to dewater after all wells are flooded out in order to recover updip oil by gravity drainage.

West Hackberry

The Camerina "D" Sand of the West Hackberry reservoir is a steeply dipping (60° average) sand pinching out against a salt dome. Water is currently being injected into two wells at a position 500 ft below the original water-oil contact. No evidence of channeling has been observed. At first, a bulge was found opposite the initial injection well; however, by completing a second injection well and balancing withdrawals and injection, the bulge disappeared. Pressure response to the program was noted six months after injection began. Currently changes in operating practice can be detected in the pressure benavior one to two months later. By balancing withdrawals with injection, the daily oil allowable has been gradually increased from 25 B/D per well to 150 B/D per well. The reservoir pressure has been increased 100 lb.

Future plans of operation are to inject gas after the water reaches the uppermost producing well in order to recover the oil located updip from the structurally highest producing well. This "attic" oil is between the last row of wells and the pinchout. Currently gas is being stored in an upper zone for this purpose.

Table I — Summary of Field Data

Location	Porter Texas	New Hope: Bacon Texas	New Hope: Hill Texas	New Hope: Pittsburg Texas	East Hackberry Louisiana	West Hackberry Louisiana	Longville Louisiana	Mamou Louisiana	Haynesville La.; Ark.	Magnolia Arkansas	Midway Arkansas	Schuler Arkansas	Wesson Arkansas
Geology													
Zone	Pettus	Bacon	Hill	Pittsburg	Camerina	Cam. "D"	L. Bell #3	Morein	Pettit	Reynolds	Reynolds	Jones	Hogg
Lithology	Sand	Lime	Sand	Sand	Sand	Sand	Sand	Sand	Lime	Lime	Lime	Sand	Sand
Average Depth	3070	7300	7400	7900	7300	9500	8150	11,550	5450	7450	6350	7470	3200
Structure	Fault Block	Anticline	Anticline	Anticline	Salt Dome	Salt Dome	Anticline	Fault Block	Anticline	Anticline	Anticline	Anticline	Offshore Bar
Closure, feet	100	100	—	95	900	1400	80	70	40	270	150	135	165
Dip, degrees	2	2	—	2	55	60	2	2	2	3-6	2	2	2
Physical Characteristics													
Sand Lithology	D, B	O	C	D, B	C, U	C	Sm S BK	C, U	O	O, H	O	L, S	C
Average Thickness	10	11	14	17	100	120	26	15	8	87	81	38	20
Acres	229	4610	1285	3305	28.5	219	520	960	14,500	4500	1800	2965	1540
Porosity, %	35	18.9	16.6	13.4	30	22.7	30.5	19.7	19.7	16.8	26	20.2	32
Permeability, md.	390	379	380	61	1500	1600	1512	51	20	1500	150	400	2770
Interstitial Water, %	35	25.4	30.6	28.7	15	19	39	33	23	20	19.7	28.5	10.6
PVT Characteristics													
Initial Reservoir Pressure	1760	3425	3425	3523	5260	4439	3631	6788	2440	3465	2920	3520	1299
Saturation Pressure	—	907	1110	1682	3960	3400	3631	5415	2440	3106	2528	3520	364
Reservoir Temperature	150	203	208	216	174	194	192	230	179	207	182	198	131
Solution Gas-Oil Ratio		256	286	577	695	550	1970	3934	520	700	283	695	63
Oil Gravity, °A.P.I.	45	43	45	49	31	31.5	46	42	42	39	36	34	32
Formation Volume Factor	—	1.233	1.287	1.456	1.327	1.29	2.142	3.34	1.331	1.44	1.24	1.45	1.078
Oil Viscosity, cp.	—	0.71	0.73	0.38	1.00	1.00	0.4	0.20	0.8	0.67	0.95	—	3.9
Water Injection Data													
Type Reservoir Drive	GC	SG	LW	SG, LW	SG	SG	SG, LW	SG, LW	SG	GC, W	SG, LW	GC	SG
Other Injection Medium	Gas	None	None	None	None	None	None	None	Gas	None	None	Gas	None
Date of Start of Water Injection	3-15-48	4-10-46	6-1-46	8-22-45	2-15-45	2-15-45	11-19-48	2-49	3-11-46	1-31-45	4-19-43	6-2-44	9-48
Reservoir Press. at Start	868	2070	2820	2400	2707	3500	2757	5000	1500	2875	2655	1455	420
3-1-51 Reservoir Pressure	822	2861	2849	1970	2550	3600	3092	4825	1250	2803	2716	1414	1234
No. of Producing Wells	7	29	14	18	9	10	10	13	70	104	46	38	62
No. of Injection Wells	1	6	3	7	1	2	3	1	38	4	4	6	6
Rate of Water Inj., B/D	260	4000	3000	2200	1500	450	5500	2000	18,000	20,265	11,960	6500	12,100
Estimated % Increase in Oil Recovery	—	144	15	30		45	86-100		60	0	168	48	164
Water Injection Systems													
Type of System	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Open	Closed
Filter Type	None	Hay	Hay	Hay	Gravel	Gravel	Hay	Sand	None	Sand	None	None	Gravel
Chemical Treatment Used	None	None	None	None	None	Scale Prev.	Scale Prev.	None	None	None	None	Algae	None
Source of Inj. Water	SS	SS, F, P	SS, FS, P	FS	SS	SS	P, SS	P, SS	FS, P	FS, P	SS, P	F, P	SS, P
Salinity of Inj. Water	10,000 ppm	SS-75,000ppm P-24,000 ppm			80,200 ppm	80,100 ppm	2% NaCl	P-48,000ppm SS-85,000 ppm	P-40,000ppm		5% NaCl		2600 ppm
Type of Inj. Pumps	O-P36	A-3, O-P36	A-3, O-P36	A-3, O-P36	C	IR	O-P36	A-5	C	G, NT	A-3, G	A-3	C, N, C-100

SYMBOLS

Sand Lithology

B — Bentonitic
C — Clean
D — Dirty
H — Heterogeneous
L — Lenticular
O — Oolitic
S — Shaley
Sm S BK — Small shale breaks
U — Uniform

Type Reservoir Drive

GC — Gas Cap
LW — Limited Water
SG — Solution gas
W — Water

Source of Injected Water

F — Fresh Water Source
FS — Fresh water supply well
P — Produced water
SS — Salt water supply well

Type of Injection Pump

A-3 — Aldrich Triplex
A-5 — Aldrich Quintaplex
C — Centrifugal
G — Gaso
IR — Ingersoll Rand
N-C100 — National C.100
NT — National Transite
O-P36 — Oilwell P-36

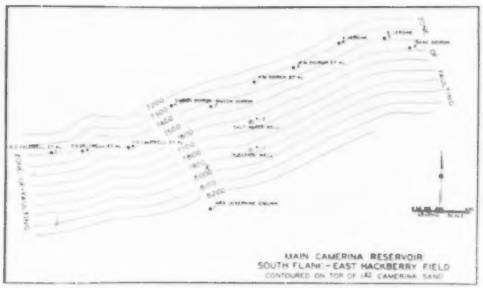

FIG. 2 — MAIN CAMERINA RESERVOIR SOUTH FLANK — EAST HACKBERRY FIELD.

Longville

Water injection was commenced in order to prevent shrinkage, maintain productive capacity and increase ultimate oil recovery. Water was used as injection medium instead of gas because it was believed that water would flush the sand more efficiently, less by-passing or channeling would occur, and the cost of water injection would be substantially smaller than gas injection.

Prior to water injection the reservoir pressure was declining at a rate of 1,100 bbl per lb. Pressure response after injection was immediate. Due to water injection it has been possible to maintain the oil producing rate and increase the reservoir pressure approximately 340 lb.

Mamou

Water injection was commenced in order to reduce shrinkage and supplement the limited water drive present only in the south end of the pool. Pressure response to water injection has been very rapid and has resulted in the elimination of pressure lows in the pool. Field performance indicates that the water front has been advancing very uniformly with very little evidence of channeling. The first well to exhibit a water cut was the closest to the injection well but it required one and one-half years of injection for the flood front to travel the 2,700 ft between the wells. Current operating policy is to maintain the reservoir pressure at a level sufficient to flow the well to depletion.

Haynesville

Water injection was commenced in order to increase oil recovery. Gas injection, for the purpose of maintaining the reservoir pressure, is currently carried on with water injection as it was thought that the reservoir had too low a permeability to accomplish pressure maintenance by water. Future plan of operation is to discontinue gas injection and flush reservoir with water.

The water injection program is a line-drive type of flood with the flood front moving areally rather than structurally. The existence of low dips and low permeability prohibited taking advantage of gravity drive. Instead the objective of the program is to sweep the injected water from one flank of the structure to the other. No water channeling is yet evident although gas injection has caused gas channeling in some areas of the pool. As the oil bank in front of the advancing water approaches a producing well, the gas/oil ratio of the well decreases to approximately solution value. The recovery due to water flood is taken to be that oil recovered after the gas/oil ratio starts to decrease. Wells nearest the water injection wells obtain the lowest recovery.

Magnolia

Water injection is handled by a Salt Water Disposal Co. which is cooperatively owned by the operators in the field. Investment was distributed on an acre-foot basis and a straight charge of two cents per barrel of produced water is assessed against operators. Excess costs are prorated on an acre-foot basis. The Salt Water Disposal Co. also conducts the field pressure surveys and operates the fresh water system of the pool. These costs are included in the above charges.

Project was initiated in order to deplete the oil reserves faster, prolong the well flow life and as a solution to the salt water disposal problem. The presence of an active water drive in the pool minimized the possibility of obtaining any increase in oil recovery due to water injection.

The principal benefits being derived from the project are the reduction in the rate of pressure decline and maintaining a higher rate of oil production as in Arkansas the oil allowable is related to pressure decline.

It is estimated that without water injection the daily oil allowable would be 90 B/D per well, instead of the 140 B/D per well the operators are currently enjoying.

Midway

As was the objective in the Magnolia Field, pressure maintenance operations were commenced in Midway in order to retard pressure decline and thus maintain producing allowables for the wells. The salt water disposal problem was also eliminated. The water injection and salt water disposal system is jointly owned by the participants.

Prior to water injection the reservoir pressure was declining at a rate of 20-30 lb per month. This decline was completely retarded within three months after the start of injection. During the eight years the project has been in operation it has been possible to increase the pressure 60 lb. The direct benefits of the program have been the maintenance of a well production rate of approximately 200 B/D per well and all wells have been able to flow their allowable.

Schuler

Water injection was commenced in the southeast portion of the pool, which area had been subject to the highest reservoir withdrawals. Injection resulted in an increase in the reservoir pressure to the point where the pressure gradient across the pool was reversed. Over all, the pressure average of the pool has been maintained since 1941, and this has resulted in a substantial saving in the cost of pumping equipment. It is estimated that the total investment cost of the pressure maintenance installations was half of what it would have cost to install pumping equipment.

Currently water is being injected in the west side of the pool which has resulted in some channeling. Calculations indicate that at the time the area is 100 per cent water cut, 40 per cent of the pore volume is water filled. This is equivalent to a stock tank oil recovery of 56 per cent of the initial oil content.

FIG. 3 — ILLUSTRATION OF CLOSED-TYPE SURFACE SYSTEM—MAGNOLIA FIELD, ARKANSAS.

Wesson

The Wesson Water Injection Project is unique in that the injection wells are located along the axis of the pool. Water is injected over the entire pay interval and caused to move radially away from the injection wells. The Hogg Sand reservoir, being an offshore bare deposit, is not underlain by water except at the southwestern end. The sand is classified as clean but does contain shale stringers along the edges. The lack of a water table and the presence of these shale stringers on the edges are the reasons for the location of the injection wells along the crest of the structure.

To date, no problem exists as to water channeling. The injected water is moving uniformly away from the injection wells. Spinner surveys indicate, however, that the water is not being injected uniformly over the entire producing interval. It is thought that the water fans out after leaving the well bore due to non-conformity of permeable streaks. Wet wells recompleted in the top of the sand for clean production indicate the oil and water are separating by gravity away from the well bore of the injection wells.

The reservoir pressure response to water injection has been particularly impressive. At the start of the project the pressure had declined to 420 lb, a point only 56 lb above the saturation pressure. As of March 1, 1951, the pressure had been increased to 1,234 lb, only 65 lb below the original reservoir pressure. This increase in the reservoir pressure is responsible for the return to flowing conditions of two-thirds of the wells and has allowed for a steady increase in the daily oil rate.

CONCLUSIONS

1. Water injection is successfully being conducted in sand and limestone reservoirs of both high and low structural relief. Pay intervals vary from 8 to 100 ft in thickness and the sand lithology ranges from uniform clean to heterogeneous dirty Bentonitic sands. The average permeability of the reservoir rock varies from 20 md to 2,772 md.

2. Chemical treatment of the injected water is being done in only two projects and in both cases for scale prevention only. In three reservoirs both fresh and salt water are being injected together without a noticeable difference in injectivity.

3. In all cases a closed system is utilized between the water supply and the injection wells. This type of system is believed responsible for the elimination of chemical treatment of the injected water.

4. The only water treatment performed in seven projects was filtering for the removal of oil and/or suspended solids. In the six other projects even filtering was not believed necessary. Injectivity is restored by acid treatment when necessary.

5. By-passing is not a serious problem as long as injection and withdrawal rates are properly balanced and the point of injection is at least several hundred feet below the oil-water interface. This allows a more uniform distribution of the flood front as it approaches the producing wells.

6. Both positive displacement and centrifugal type injection pumps are being used with equal success. The selection of the type and size of the pump required is dependent upon the volumes and pressures to be handled.

7. The benefits being derived from pressure control by water injection are increased oil recovery, prolongation and/or restoration of flow life, lower lifting costs, shorter producing life, increase or maintenance of producing rates, higher allowables, and reduction or elimination of waste water disposal problems.

ACKNOWLEDGMENT

The authors thank the managements of the Seaboard Oil Co. of Delaware and the Honolulu Oil Corp. for permission to publish this paper. Appreciation is also expressed to the individuals and companies who so generously contributed information on the operation of the various projects.

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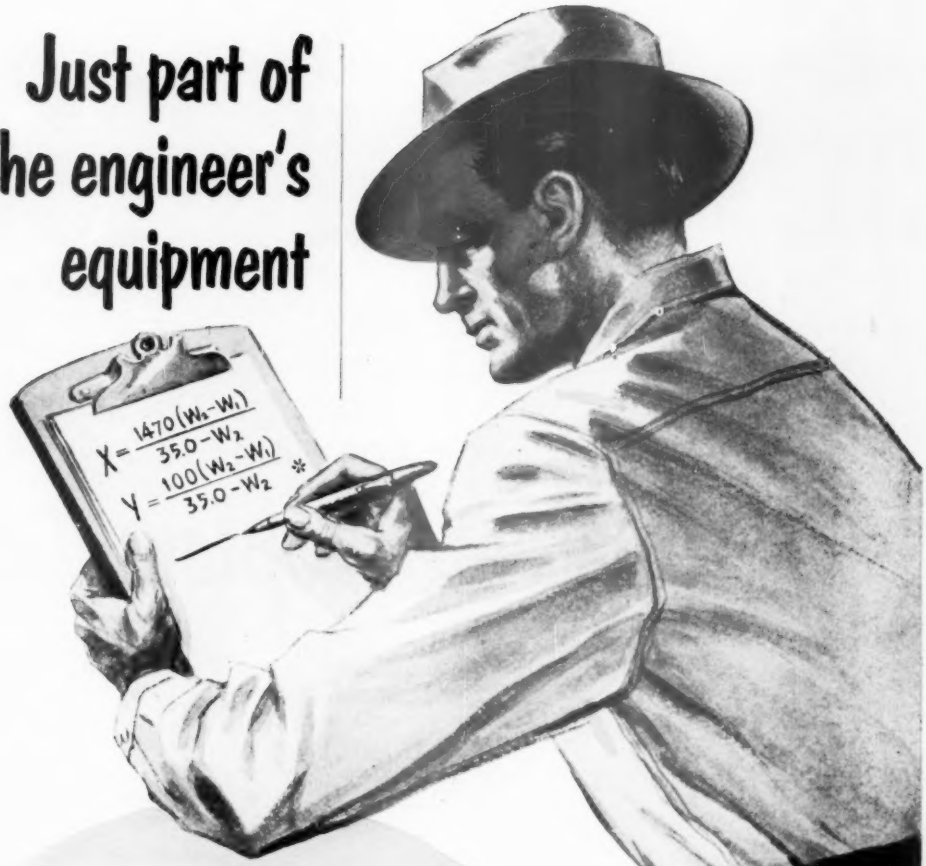
Just part of the engineer's equipment



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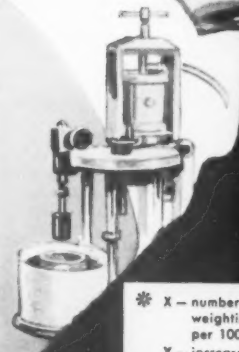

* X — number of 100-lb sacks of weighting material needed per 100 bbls. of mud.
Y — increase in mud volume due to weighting.
W_1 — initial mud weight (lbs./gal.)
W_2 — final mud weight (lbs./gal.)

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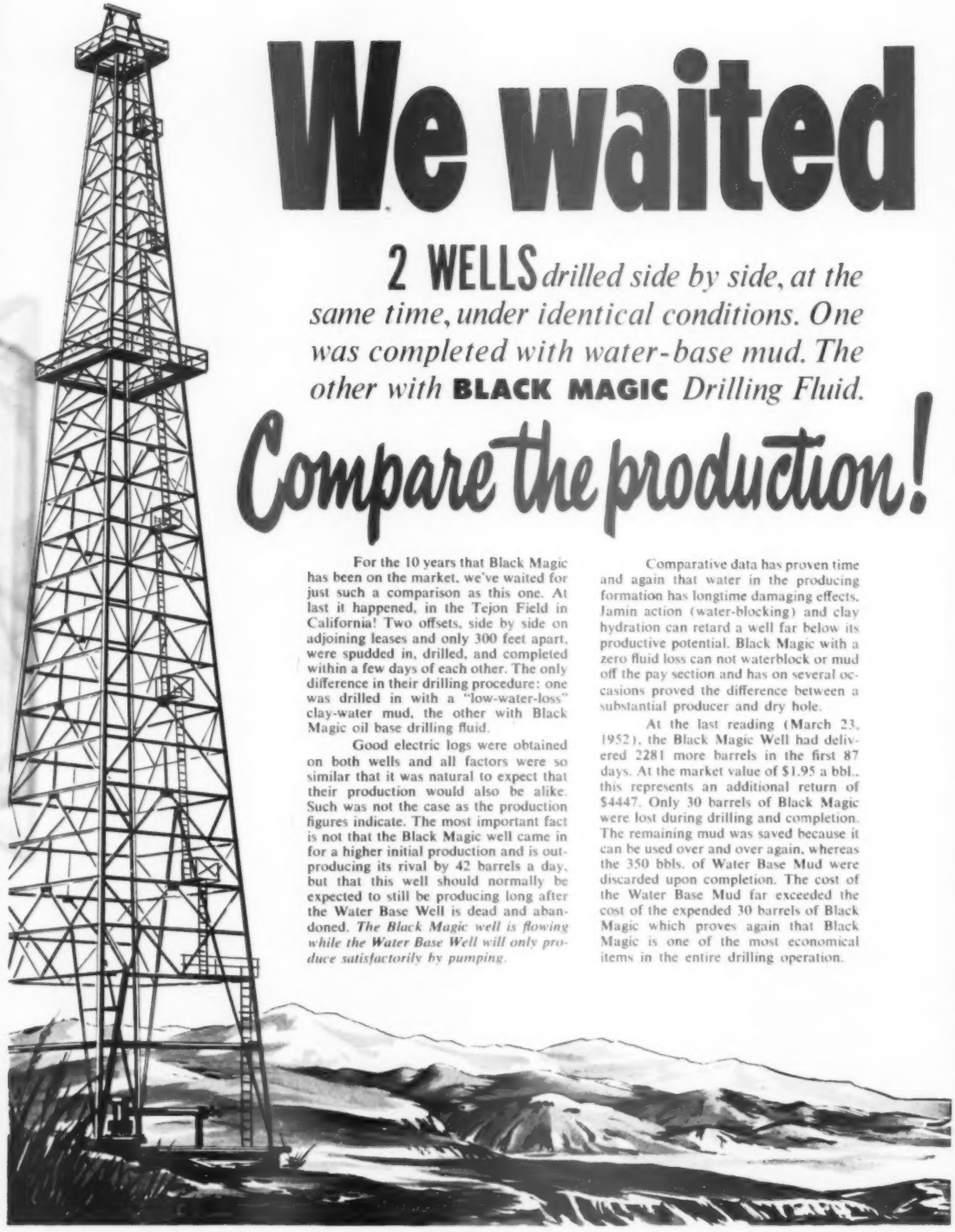
Compare the production!



For the 10 years that Black Magic has been on the market, we've waited for just such a comparison as this one. At last it happened, in the Tejon Field in California! Two offsets, side by side on adjoining leases and only 300 feet apart, were spudded in, drilled, and completed within a few days of each other. The only difference in their drilling procedure: one was drilled in with a "low-water-loss" clay-water mud, the other with Black Magic oil base drilling fluid.

Good electric logs were obtained on both wells and all factors were so similar that it was natural to expect that their production would also be alike. Such was not the case as the production figures indicate. The most important fact is not that the Black Magic well came in for a higher initial production and is outproducing its rival by 42 barrels a day, but that this well should normally be expected to still be producing long after the Water Base Well is dead and abandoned. *The Black Magic well is flowing while the Water Base Well will only produce satisfactorily by pumping.*

Comparative data has proven time and again that water in the producing formation has longtime damaging effects. Jamin action (water-blocking) and clay hydration can retard a well far below its productive potential. Black Magic with a zero fluid loss can not waterblock or mud off the pay section and has on several occasions proved the difference between a substantial producer and dry hole.

At the last reading (March 23, 1952), the Black Magic Well had delivered 2281 more barrels in the first 87 days. At the market value of $1.95 a bbl., this represents an additional return of $4447. Only 30 barrels of Black Magic were lost during drilling and completion. The remaining mud was saved because it can be used over and over again, whereas the 350 bbls. of Water Base Mud were discarded upon completion. The cost of the Water Base Mud far exceeded the cost of the expended 30 barrels of Black Magic which proves again that Black Magic is one of the most economical items in the entire drilling operation.

10 years for this

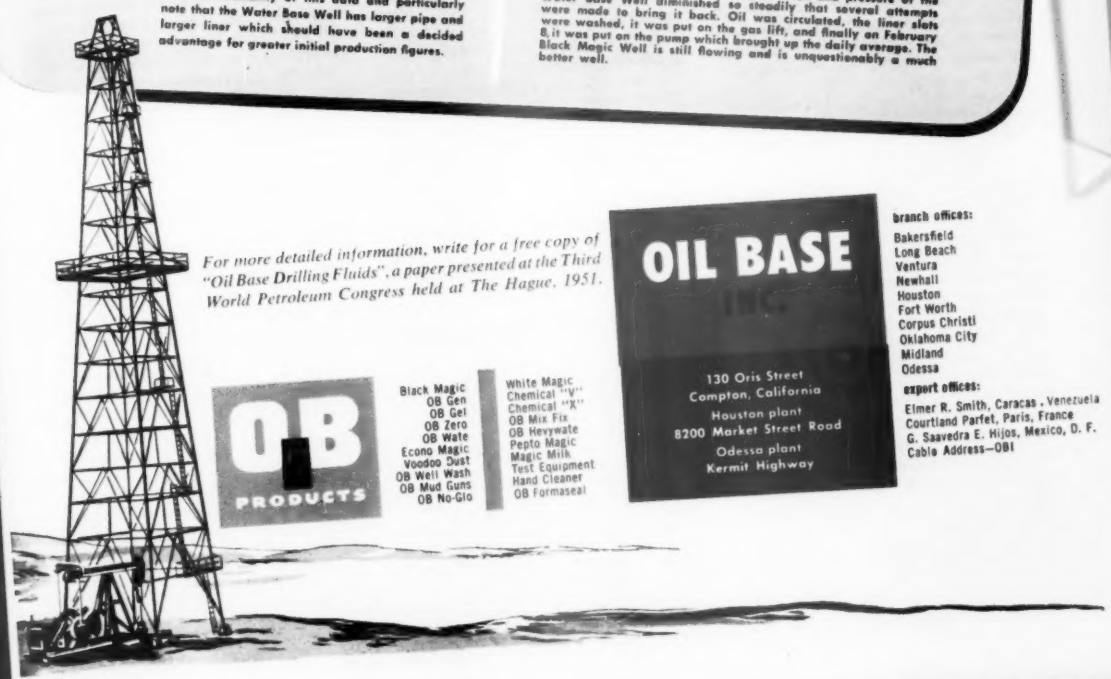
completion data	Water Base Well *	Black Magic Well
Completed	Dec. 22, 1951	Dec. 30, 1951
Total Depth	2936'	2967'
Casing size	8⅝"	7"
Casing set at	2801'	2835'
Liner size	6⅝"	5⅛"
Liner mesh (slots)	.100	.080
Liner depth	2782' to 2936'	2813' to 2967'
Liner length	154'	154'
Productive Interval	89'	90'

*The water base well is 30' higher structurally.

Note the similarity of this data and particularly note that the Water Base Well has larger pipe and larger liner which should have been a decided advantage for greater initial production figures.

production data	Water Base Well	Black Magic Well
Initial Production	120 B/D*	206 B/D*
Choke size	16/64"	20/64"
Tubing pressure	80 lbs.	90 lbs.
Casing pressure	0 lbs.	10 lbs.
Production (Jan. 7, '52)	75 B/D	128 B/D
Choke size	20/64"	20/64"
Tubing pressure	35 lbs.	90 lbs.
Casing pressure	0 lbs.	160 lbs.
Production (March 23, '52)	99 B/D	141 B/D
Choke size	(pumping)	20/64"
Tubing pressure	20 lbs.	75 lbs.
Casing pressure	600 lbs.	900 lbs.
Total Production (Mar. 23)	7,563 bbls.	9,844 bbls.
Average daily production (from start)	80 B/D	113 B/D

*Both wells came in flowing but production and pressure of the Water Base Well diminished so steadily that several attempts were made to bring it back. Oil was circulated, the liner slots S, it was put on the gas lift, and finally on February Black Magic Well is still flowing and is unquestionably a much better well.



For more detailed information, write for a free copy of "Oil Base Drilling Fluids", a paper presented at the Third World Petroleum Congress held at The Hague, 1951.

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Application of the Carter Analyzer to Field Problems

Reported by Robert H. Burke
Pacific Junior Group

J. Earl Warren of the California Research Corp. spoke last month to members of the Junior Section of the Pacific Petroleum Chapter at Downey, Calif. His subject was "Application of the Carter Reservoir Analyzer to Field Problems."

The Carter Analyzer was designed to study the pressure-production behavior of oil reservoirs. It can be used to predict the future performance of a single field enclosed by an aquifer. It will also determine the effect of production from one field upon the performance of another field, when both fields are connected by a common aquifer. Determination of the effect of production from one section of a field can be handled. The Carter Analyzer can also be used to study pressure build-ups in single wells.

The Carter Analyzer was first developed for reservoir studies by W. A. Bruce of Carter in 1943. The operation of the analyzer is based on the analogy between the equation of fluid flow and electrical current flow. Analogous quantities in the equations are listed as follows:

FLUID	ELECTRICAL
Compressibility	Capacitance
Resistance	Resistance
Volume	Charge
Volume Flow Rate	Current
Pressure	Voltage
Time	Time

The basic data required to make a study of a single field, where the field is treated as a point sink in an aquifer, are a geologic description of the field and aquifer, estimates of fluids in place, core analysis data (porosity, permeability, etc.), original reservoir pressure, PVT relations, and pressure and production histories.

Application of the analyzer to a point sink study of a single field and aquifer is divided into three parts. First, an electrical network analogous to the field and aquifer and electrical functions analogous to the withdrawal and compressibility functions of the field are set up in the analyzer. Second, because complete data are seldom available, the analyzer is run and adjustments made in the electrical current until the analyzer determined pressure history matches the field observed pressure history. The third and final step of the study is to make predictions. After the field history has been matched, it is then possible to predict production characteristics of the field for particular production programs. Predictions are usually extended for a period equal to that of the history.

J. EARL WARREN

The analyzer is subject to certain limitations. As such, it must be applied intelligently. For example, the analogy between fluid flow and electrical current flow in the analyzer is valid only for single phase flow. The analyzer can account for changes in saturation and compressibility, but will not account for relative permeability changes. Thus, pool studies and well build-up studies are made on undersaturated reservoirs or over the time interval of history where the flow to the well or in the pool is essentially single phase.

The Carter Analyzer has proved itself a useful tool in reservoir engineering studies. It does not give the complete answer on how to produce oil in the most economical way, but it does help guide the engineer to an intelligent answer. ★ ★ ★

Officers Named at Okla. IT

The final meeting of the semester for the Petroleum Club of Oklahoma Institute of Technology was held on Thursday, May 20. A. T. Woods, instructor of mechanical engineering, was elected to continue his post as sponsor. The elected officers for the fall semester of 1952 are president, Dick A. Rundle; vice-president, Marvin K. Dishman; corresponding secretary, Jerry M. McCutchan; secretary, James G. Bonsall; treasurer, Curtis Moren. ★ ★ ★

Student Papers Presented At Texas A&I Meeting

The meeting last month of the AIME Student Chapter at Texas A&I College was opened with a banquet attended by 21 members of the Student Branch and 15 members of the AIME Southwest Texas Section. Dinner was served in Loftin Hall on the campus at Kingsville, Tex.

At the conclusion of the banquet the meeting adjourned to the new Engineering Building. President Calvert introduced Chairman Harry Vaughan of the Southwest Texas Section and Counselor John Crutchfield and Sponsor Frank Dotterweich of the Student Chapter.

At the meeting three student papers were presented that had previously been selected by an AIME committee from a group of papers prepared by members of the Student Chapter. At the conclusion of the presentation, the representatives of the Southwest Texas Chapter voted first, second and third places as follows:

First Place: "Surface Equipment Layout Considerations for a Pressure Depletion Oil and Gas Reservoir," by John Moon.

Second Place: "Jet Type Drilling Bits," by Kenneth Kaigler.

Third Place: "Design of a Magnesium Anode Corrosion Control System," by W. C. Calvert.

Each of the three students received a book, "Petroleum Conservation," and a letter from Joe B. Alford, Executive Secretary of the Petroleum Branch AIME. The AIME group voted to send the three papers to New York and enter them in the nation-wide contest which will provide $100 each for the first three papers selected. ★ ★ ★

Application of Geologic Principles

Reported by J. A. Klotz
Pacific Technology Forum

Mason L. Hill, assistant chief geologist for the Richfield Oil Corp., continued the series of ten talks on "Principles of Petroleum Production," that is being sponsored by the Pacific Technology Forum. Hill's talk, "Application of Geologic Principles to Petroleum Exploration and Exploitation," was the second talk of the series. In March, R. A. Peterson of the United Geophysical Co. presented the first talk on petroleum prospecting. The remaining eight talks will also be given by men who are authorities in their respective fields: core analysis, well logging, reservoir fluids, fluid mechanics, solution gas drive, gravity drainage, natural water drive, and condensate production.

Hill did not try to teach the principles of geology to the group of about 50 petroleum engineers who comprised the audience. Instead, he used samples of these principles to show the deficiencies of geology as an effective exploration tool and deficiencies of geologist, petroleum engineer and manager as an effective exploration team. The deficiencies of the team arise largely from failure of engineers and managers to understand the shortcomings of geology. Geology as a science is far from quantitative: at best, the recommendation of a geologist to drill or not to drill is an educated guess. The guess is, of course, guided by sound principle, and is more probable to be right than a similar guess by a nongeologist, but reasons for the recommendation cannot be expressed quantitatively. Managers and engineers are, however, accustomed to working with dollars and cents, with barrels of oil, with pressures and flow rates, all of which can be talked about with exact numbers. They quickly become impatient with geologists who speak only about qualitative ideas.

In order to illustrate the guesses that geologists make and to point out improvements that are needed, Hill described some of the principles used to choose exploration prospects. The guiding principle of all geology is the "law of uniformitarianism;" that is, current events, such as Colorado River erosion, are a key to events that have happened in the past. This principle is difficult to apply, however, because surface events happen so slowly that they are hard to visualize; geologists would like to know more about events inside the earth.

The fundamental unit of the science of geology is rock, and of the three genetic groups of rocks, igneous, metamorphic, and sedimentary, Oil usually is found only in sedimentary rocks. Unless igneous and metamorphic rocks are fractured or altered chemically, they do not possess the porosity and permeability required of reservoir rocks.

Oil is found in, or closely associated with, sediments deposited in geosynclines. These are large depressions in the earth's surface into which shallow seas have advanced. (The Williston Basin is an excellent example.) Oil apparently forms in the sediments below the floor of the sea, and because it is lighter than the water surrounding it in these sediments, the oil migrates upward. When it reaches a low permeability layer in the sediments, the oil moves horizontally under this layer toward the upturned edges of the geosyncline saucer. Oil that forms reservoirs has accumulated in structural traps during its migration toward the edge of the geosyncline. In 1854-60, I. C. White perceived the relationship between anticlines and oil reservoirs; since that time many types of traps (faults, unconformities, and facies changes) have been discovered.

The first step of a geologist exploring for oil in a new area is to determine from surface indications the outlines of the geosyncline. The next step is to map the traces and stratification attitudes of outcrop contacts between sediments of different ages within the basin. The third step is to establish the age of each sediment or at least the age of each sediment relative to its neighbors. Usually, geologists assume that overlying sediments are younger than the sediments beneath them; but in some areas, faults or overturned folds have placed old beds on top of younger beds. In these areas, microscopic examination of fossils and comparison of these fossils with similar fossils from an area where sediment ages are known indicate probable ages of the unknown beds.

When all available surface data have been gathered, the next step is to draw subsurface contour maps and vertical cross-sections. These are impossible to draw accurately; extrapolation of dips and strikes measured at the surface to 10,000 ft subsurface may indicate a completely erroneous position for the crest of a fold. The final step, drilling of a test well, is the only method for determining the accuracy of the geologist's preparatory guess work and the only method for determining, even if the geologist's guesses are accurate, whether or not the structure contains oil and whether or not the properties of the oil and of the reservoir rock are such that the oil can be produced economically.

In summary, Hill listed the following projects to which geologists and the oil industry should turn their energies so that they may become more effective oil finders.

Geologic effort should be intensified. Management should increase salaries offered to geologists to attract more men and better men to geology. Geologists, in turn should acquaint themselves with other parts of the company; with management and with engineering. Geologists should sell themselves and the science of geology more aggressively to management. More geologists should devote their time to fundamental researches that pertain to the problems of petroleum geology; such as, marine sedimentation and the mechanism of trap forming.

More test holes should be drilled. Development of a cheap method for drilling 10,000-ft core holes would facilitate collection of subsurface data. Wildcat wells should be drilled for the

Continued on Page 10, Section 2

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DISCUSSION OF THIS AND ALL FOLLOWING TECHNICAL PAPERS IS INVITED

Discussion in writing (3 copies) may be sent to the Editor, *Journal of Petroleum Technology*, 408 Trinity Universal Bldg., Dallas 1, Texas, and will be considered for publication in the Transactions volume *Petroleum Development and Technology*. Discussion will close December 31, 1952. Any discussion offered thereafter should be in the form of a new paper.

THE RESISTIVITY OF A FLUID-FILLED POROUS BODY

J. E. OWEN, GEOPHYSICAL RESEARCH CORP., TULSA, OKLA.

ABSTRACT

A model of a porous body is presented in which the pore space consists of a system of voids and interconnecting tubes. Relationships between porosity and resistivity formation factor are determined partly by calculation, partly by experiment. Constriction effects characteristic of the model are shown to be sufficient to account for high formation factors. It is shown that constriction may be combined with moderate amounts of tortuosity to give model pore systems exhibiting to a first approximation porosity and resistivity properties similar to those of natural porous bodies.

INTRODUCTION

The relationship between the electric resistivity of a fluid-filled porous body and the geometry of its pore space is so complex that the calculation of the resistivity of a natural porous rock is a practical impossibility. Both the resistivity of a body and its porosity are measurable quantities, however, and previous successes at relating them have been reached by an empirical approach. Efforts at obtaining theoretically derived formulae relating them have generally been unsatisfactory. One of the reasons for this may lie in the pore geometry that has been assumed.

THE TORTUOSITY CONCEPT

A parameter called the formation factor is useful in discussing the resistivity of a fluid-filled porous body. This parameter is the ratio of the resistivity of a fluid saturated porous body to the resistivity of the saturating fluid. Formation factors are often available from measurements on cores or from electric logs, and many attempts have been made to correlate formation factors and porosities of geological formations. Whenever a successful correlation is found, the engineer working with electrical logs has a useful tool for the determination of porosities of pay sections. One of the more successful formulae applicable to these correlations is the familiar equation empirically obtained by Archie.[1]

$$F = \phi^{-m} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

in which F is the formation factor, ϕ is the porosity, and m is an exponent called the cementation factor. When the formula applies, the cementation factor usually is found to be between 1.3 and 2.2.

The values for formation factors experimentally obtained are often higher than simple pore geometry would lead one to expect. In an effort to account for such high values certain formulae have been derived based on a so-called "tortuosity concept." In deriving these formulae a synthetic porous body is usually assumed in which the solid material is an electrical non-conductor, and in which the pore system consists of three sets of fluid-filled tubes of uniform diameter connecting opposite faces of the body which, for convenience, is considered to be cubical in shape. The three sets of tubes account for the whole of the effective porosity of the body, and usually, it is specified that they do not interconnect. By considering that the pore tubes are not straight but tortuous, their resistance to the flow of electric currents can be made as high as needed to explain high formation factors. Such an explanation has some basis in fact, but it appears that the tortuosity concept is often incorrectly applied when other factors are largely responsible for observed high resistivities. Recently, Wyllie and Spangler have recognized that tortuosity as calculated by conventional formulae has little if any physical significance.[2]

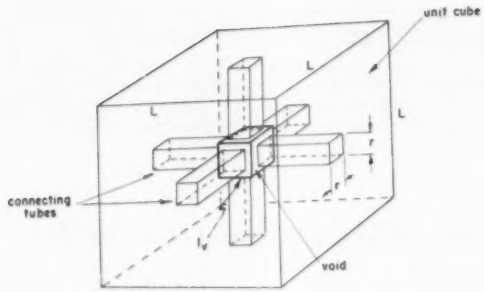
RESISTIVITY AND THE CONSTRICTION CONCEPT

Any explanation of high formation factors which depends solely on tortuosity of uniform pore paths necessarily ignores the effect that variations in the cross-sectional area of the conducting paths have on the resistivity of a body. Although, as previously pointed out, the calculation of such paths for an actual body is impossible, it will be shown that a synthetic pore network can be devised which will yield to analysis, and lead to results in agreement with the experimental data represented by Equation (1).

The porous body to be considered is assumed to be homogeneous and isotropic or, for present purposes, identical in its characteristics in the three directions parallel to its coordinate axes. It will be assumed to be built of identical unit cubes, each of which contains a single pore network connecting all faces of the unit cube. A unit of such a pore network is shown

[1] References given at end of paper.

Manuscript received in the Petroleum Branch office Jan. 22, 1952.



F.G. 1 — UNIT CUBE OF SYNTHETIC POROUS BODY.

in Fig. 1. The solid portion of this unit cube is electrically non-conducting. Within the unit cube is a cubical void centrally located, with faces parallel to corresponding faces of the unit cube. The connecting tubes are square in cross section normal to the axis of the tube. In Fig. 1 these connecting tubes are shown with their axes normal to the faces of the unit cube. A more general case, however, is that of Fig. 2. In this figure a cross section of a portion of a synthetic porous body is shown in which the connecting tubes make an angle θ with the normal faces of the unit cube. Such a porous body exhibits both constriction and tortuosity.

The electric resistance between two of the opposite faces of a unit cube is the sum of the resistances through the tubes connecting the void with those faces, and the resistance through the void cube measured from the contacts made with the void faces by the two tubes directly in the path of current flow. This resistance is somewhat greater than would be the case if each contact were made with the entire face of the void cube. The effect of the four side tubes is to lower the resistance of the void. Calculations of these two effects would be difficult to carry out, and their determination was therefore made experimentally. A series of simple experiments was carried out in which a bakelite box cubical in shape was used as a model for the void. Square metallic electrodes were placed at the midpoints of two of the opposite faces of the cube which was then filled with a saline solution. The resistance between the electrodes was measured for a number of electrodes of different areas. The results are given in Fig. 3 in which the value plotted as the ordinate is the ratio of the resistances measured through the cube as the size of the electrode was varied, to the resistance measured when the electrode covered the entire face of the cube. This resistance ratio is plotted as a function of the term C which will be called the constriction factor. It is defined as

$$C = \frac{l_v}{r} \quad \ldots \ldots \ldots \ldots \ldots \quad (2)$$

In Fig. 1 this is seen to be the ratio of an edge of the void cube to a side of the square which is the cross section of a connecting tube. C, in the experimental work, is the ratio of the lengths of one edge of the void cube and one edge of the electrode.

The influence of the side tubes on the resistance through the void was determined by measurements on a model for the limiting case in which the void has become merely the intersection of the connecting tubes. This is obviously the case for which the shunting effect of the side tubes is the greatest, and is the case for which $C = 1.0$. For this case it was found that the ratio of the resistances of a void cube with and without the four side tubes is 0.5. The shunting effect of the side tubes decreases quite rapidly with increasing values of C, and for values of $C > 3$ this effect is negligible. By combining the data from the model experiments, the curve of Fig. 4 was prepared. In this figure the factor f represents the correction factor to be applied to the resistance shown by the void of Fig. 1 in which the resistance of the void is first calculated as though contact were made with the entire face of the void cube. This correction factor may be shown to be slightly in error when $C < 1.4$ and simultaneously $\phi > 0.3$, but this combination of conditions is not of particular interest in this paper.

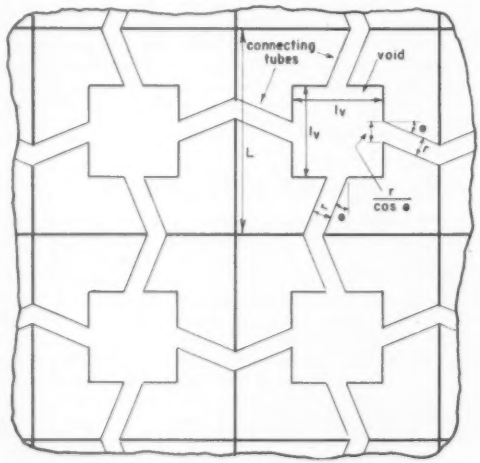
Let each connecting tube connect the void and face of the cube as shown in Fig. 2. The tube makes an angle θ with the normal to the face of the cube to which it connects. The intersection of the tube with the face of the void or the face of the cube, is a rectangle $r \cdot r/\cos\theta$. The resistance through the void from the rectangular intersection is to a sufficiently close approximation the same as the resistance from squares of the same equivalent area. The corresponding value for the side r' of the equivalent square contact is

$$r' = \frac{r}{\sqrt{\cos\theta}} \quad \ldots \ldots \ldots \ldots \quad (3)$$

The curve of Fig. 4 applies to a pore network in which the angle $\theta = 0$. Hence the constriction factor to use in determining f for the case in which $\theta \neq 0$ is a value of C', corresponding to the value r', or

$$C' = \frac{l_v}{r'} = \frac{l_v\sqrt{\cos\theta}}{r} = C\sqrt{\cos\theta} \quad \ldots \ldots \quad (4)$$

The resistance R from one face of a unit cube to the opposite face is the sum of the resistance R_v through the void and



F.G. 2 — CROSS SECTION THROUGH FOUR UNIT CUBES OF SYNTHETIC POROUS BODY WITH TORTUOUS CONNECTING TUBES. VALUES USED: $C = 5.0$, $\theta = 22.5°$ or $T^{1/2} = 1.08$, $\phi = 0.10$.

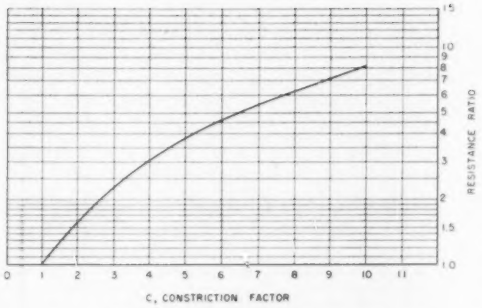


FIG. 3 — EXPERIMENTAL VOID CUBE RESISTANCE DATA.

the resistance R_t through the tubes connecting the void and these faces.

$$R_v = \rho_w \frac{f}{l_v} \quad \ldots \quad (5)$$

and,

$$R_t = \frac{\rho_w (L - l_v)}{r^2 \cos\theta} \quad \ldots \quad (6)$$

In these equations ρ_w is the specific resistivity of the fluid filling the pore space. The factor f is obtained from Fig. 4 in any particular case for the value of C being considered.

$$R = R_v + R_t = \rho_w \left(\frac{f}{l_v} + \frac{L - l_v}{r^2 \cos\theta} \right) \quad \ldots \quad (7)$$

The resistivity ρ of the porous body is

$$\rho = RL = \rho_w L \left(\frac{f}{l_v} + \frac{L - l_v}{r^2 \cos\theta} \right) \quad \ldots \quad (8)$$

The formation factor F is defined as

$$F = \frac{\rho}{\rho_w} = L \left(\frac{f}{l_v} + \frac{L - l_v}{r^2 \cos\theta} \right) \quad \ldots \quad (9)$$

The porosity ϕ of the body is given by

$$\phi = \frac{l_v^2 + \dfrac{3(L - l_v) r^2}{\cos\theta}}{L^2} \quad \ldots \quad (10)$$

From (9) and (10)

$$F = L \left(\frac{f}{l_v} + \frac{3(L - l_v)^2}{(L^2 \phi - l_v^2) \cos^2 \theta} \right) \quad \ldots \quad (11)$$

The term for tortuosity may now be introduced and is defined as $T^{1/2} = \dfrac{1}{\cos\theta}$. For convenience, also, let $a = \dfrac{r}{L}$ and $b = \dfrac{l_v}{L}$. Since $C = \dfrac{l_v}{r}$, it follows that $C = \dfrac{b}{a}$. The porosity of a body, from Equation (10), can be expressed

$$\phi = b^3 + 3(1 - b) a^2 T^{1/2} \quad \ldots \quad (12)$$

Equation (11) reduces to

$$F = \frac{f}{b} + \frac{3(1 - b)^2 T}{\phi - b^3} \quad \ldots \quad (13)$$

This may also be expressed in the form

$$F = \frac{f}{b} + \frac{(1 - b) T^{1/2}}{a^2} \quad \ldots \quad (14)$$

APPLICATION OF FORMULAE

From the formulae that have been developed, the curves of Fig. 5 have been prepared. Here are given calculated formation factors of synthetic porous bodies for four values of porosity, and corresponding to each of these, three values of tortuosity. It is interesting to note that for any chosen porosity and tortuosity, the formation factor is nearly independent of the constriction factor for values of C less than two. For higher values of C, however, F increases rapidly with increasing constriction. High values of formation factor that are observed in actual porous bodies can thus be accounted for by combinations of tortuosity and constriction effects or, if desired, by constriction alone. For example, a porous body with a porosity of 0.2 and a formation factor of 50 may be said to be equivalent to a synthetic porous body of the same porosity and with any of the following combinations of constriction and tortuosity:

$T^{1/2} = 1.0$ $(\theta = 0°)$,	$C = 5.75$;
$T^{1/2} = 1.08$ $(\theta = 22\frac{1}{2}°)$,	$C = 5.6$;
$T^{1/2} = 1.41$ $(\theta = 45°)$,	$C = 4.8$

Any of these values or other that can be interpolated from the curves of Fig. 5 are geometrically reasonable, whereas the extremely high angles of tortuosity required by previously derived formulae based solely on tortuosity concept are difficult to accept as being representative of conditions in a porous body. This is illustrated by the example chosen here, assuming no constriction, one -third of the total porosity in each set of non-interconnecting tortuous tubes corresponding to the three coordinate axes of the body, and using formulae previously given in the literature.[3] The average or effective angle of tortuosity is approximately 72°. Based on the conventional tortuosity concept, values of tortuosity as high as 200 have been reported.[4] Such a value of tortuosity as defined in this reference corresponds to a flow path at an angle of 86° to the general direction of current flow through the body. It is hardly conceivable that the true direction of current flow through a porous body is so nearly perpendicular to the direction in which resistivity measurements are made.

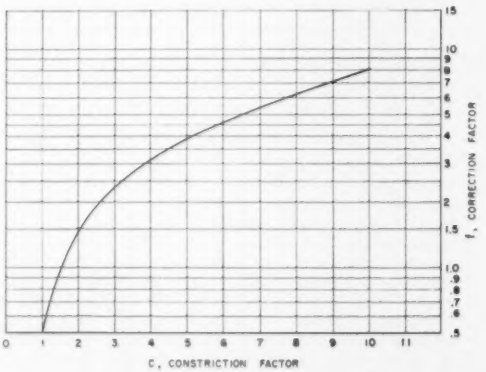


FIG. 4 — f, CURRENT DISTRIBUTION CORRECTION FACTOR vs C, CONSTRICTION FACTOR, $T^{1/2} = 1$.

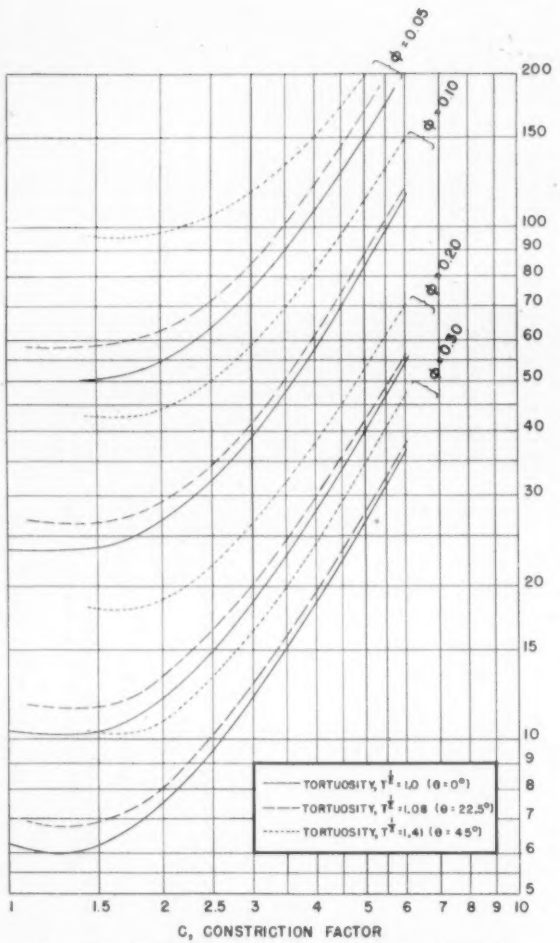
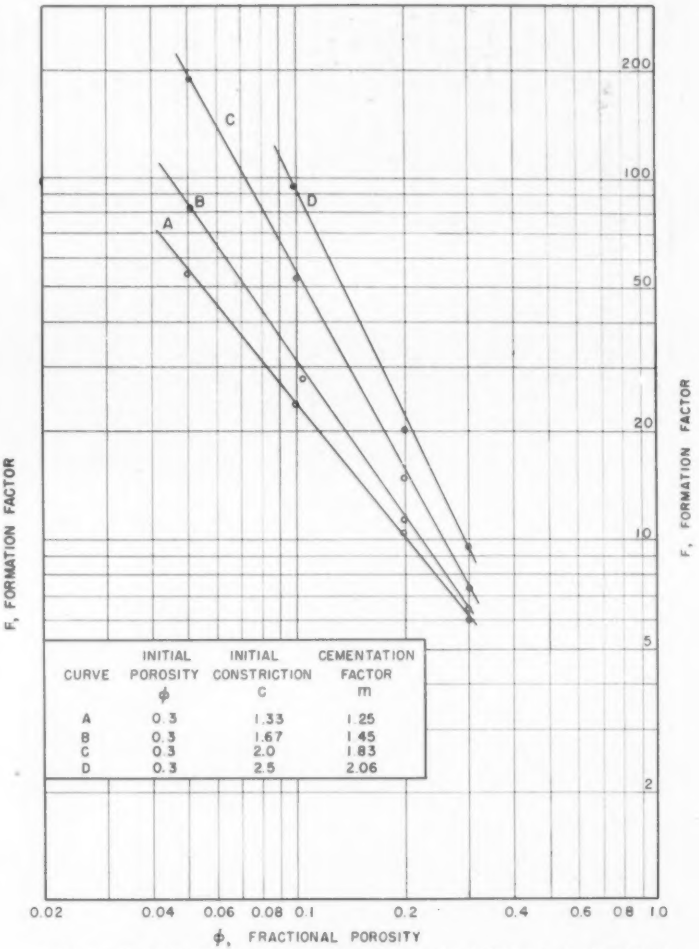

φ = 0.05
φ = 0.10
φ = 0.20
φ = 0.30
TORTUOSITY, T² = 1.0 (θ = 0°)
TORTUOSITY, T² = 1.08 (θ = 22.5°)
TORTUOSITY, T² = 1.41 (θ = 45°)
F, FORMATION FACTOR
C, CONSTRICTION FACTOR

FIG. 5 — RELATION BETWEEN FORMATION FACTOR F AND CONSTRICTION FACTOR C OF VOID-TUBE NETWORK. ϕ = FRACTIONAL POROSITY.



CURVE	INITIAL POROSITY ϕ	INITIAL CONSTRICTION C	CEMENTATION FACTOR m
A	0.3	1.33	1.25
B	0.3	1.67	1.45
C	0.3	2.0	1.83
D	0.3	2.5	2.06

FIG. 6 — RELATION BETWEEN FORMATION FACTOR F AND POROSITY ϕ FOR VOID-TUBE NETWORK WITH PROGRESSING CEMENTATION, $T^{1/3} = 1$.

The formulae used in obtaining the curves of Fig. 5 are based on voids cubical in shape, and connecting tubes square in cross section, and the discussion thus far has been limited to tubes and voids having these shapes. It is obvious, however, that uniform tubes of any shape having the same cross-sectional area will exhibit the same electric resistance as square tubes. A spherical void of the same volume can also be substituted for a cubical one with approximately the same overall results. Thus the particular shape of the voids and connecting tubes used in this analysis is not essential to the constriction concept or to its use in explaining high formation factors. The pore network to which this discussion and the derived formulae may be applied, then, consists of any regular system of voids and connecting tubes similar to the one investigated here. The particular pore network described was chosen for convenience in experimentation but no objection is seen to the acceptance of such a network as a synthetic reference body in terms of which constriction and tortuosity of natural porous bodies may be expressed. This analysis can be extended to include anisotropic bodies by using in the three directions through the body connecting tubes of different sizes and with different tortuosities.

CEMENTATION AND THE CONSTRICTION FACTOR

Earlier in this paper it was pointed out that empirical correlations have been established by various investigators relating porosities and formation factors, and that one of the best known is the one expressed by Equation (1). It is of interest to consider the effect of cementation upon the pore network of Fig. 1 when certain assumptions are made regarding initial conditions and the manner in which cementation takes place.

Consider, for example, a case in which samples taken from a particular porous body vary widely in porosity solely because of differences in the amount of cementing material present. Before the deposition of the cementing material these porous body samples are considered to have been identical in the general nature of their pore spaces, and corresponding to this initial condition, the equivalent pore network of the type of Fig. 1 (no tortuosity) will be considered as having had a fractional porosity of 0.3 and a constriction factor of 1.33. In other words, the pore body before cementation was characterized by voids and connecting tubes of a size giving a porosity of 0.3 and with the connecting tubes nearly as large as the voids themselves. Conditions which controlled the deposition of cementing material in the pore space, however, varied from sample to sample and thus the final porosities differed. Corresponding to the actual case of cementation it will be assumed that in the equivalent pore network of Fig. 1 a uniform deposition of cementing material has taken place on the walls of the voids and the walls of the connecting tubes. For any amount of deposition it is possible, then, to calculate the new porosity of the body and the resulting formation factor by use of the formulae developed here. In this manner the straight line *A* of Fig. 6 was obtained from an initial condition of $\phi = 0.3$ and $C = 1.33$, by assuming that the cementation process deposited a uniform layer of material on the walls of the voids and connecting tubes. The slope of line *A* is found to be 1.25.

Similarly, with initial porosities of 0.3 and initial values for *C* of 1.67, 2.0, and 2.5 the porosities and formation factors with progressing cementation plot in Fig. 6 quite close to the straight lines *B*, *C*, and *D*, respectively, and with slopes that are tabulated as cementation factors from their correspondence to the exponent of Equation (1). Throughout a rather wide range of porosities the value of *m* under a progressing cementation process is thus approximately constant, and is a function of the values of ϕ and *C* at its beginning. Obviously, if the calculated porosities and formation factors were related precisely as described by Equation (1), lines *A*, *B*, *C*, and *D*, if extended, would pass through the point (1, 1). This they will not do if extended as drawn, and hence the data are somewhat better represented by an equation of the form $F = a\phi^{-m}$.

Experimental work reported by Archie,[1] indicates that unconsolidated sands obey the relation given by Equation (1) in which *m* is approximately 1.3. It may be assumed that his unconsolidated sands were composed of grains of fairly uniform size when the porosities that he observed were as great as 0.3. A sand of this type has a low constriction factor, as it does not contain large voids with small connecting tubes. On the other hand, it is likely that the low porosity unconsolidated sands that Archie used were mixtures of grains of different sizes, or were silty. Fine materials would be expected to clog a part of the smaller passageways through a sand as well as to fill a portion of the voids. It makes little difference whether, from an initial condition of high porosity, low porosity is obtained in a sand by reducing the somewhat smaller passageways with loose, relatively fine material, or by a cementation process of the kind previously described. The high porosity conditions for unconsolidated sand, then, correspond to the initial conditions for Curve *A* of Fig. 6, and the calculated value of *m* that is observed with changes in porosity is seen to be approximately the same as that observed experimentally.

Archie also found that highly cemented sandstones are characterized by a high value of *m*. Sandstones that are highly cemented and yet have good porosity must have been highly porous before cementation and hence necessarily contained large voids. The process of cementation, then, resulted in a relatively high value for *C* even at a porosity of 0.3. Curves such as *C* or *D* of Fig. 6 may therefore be expected to apply to such sandstones as cementation proceeds from the condition described. It will be seen that the values of *m* for curves *C* and *D* correspond to the values observed by Archie for highly cemented sandstones.

CONCLUSIONS

The void and tube network described in this paper appears to meet many of the requirements for a synthetic porous body which may be used as an equivalent of a natural porous body. The equations for the flow of electric current through this network have been derived. These equations show how constriction effects can cause porous bodies to exhibit high formation factors. Such a void and tube network is suggested, therefore, as being more nearly analogous to conditions within a natural porous body than is a uniform diameter tube system which requires high tortuosity values to explain large formation factors.

The work in this paper is not sufficiently complete to enable the full determination of the geometry of a synthetic porous body in all ways equivalent to a natural porous body. In an example that was chosen it was found that for a body with a porosity of 0.2 an infinite number of combinations of tortuosity and constriction factors may be chosen to give a formation factor of 50. For moderate values of tortuosity, however, the constriction factors lie within a narrow range. The actual size of the unit cube for the synthetic porous body does not enter into the calculations, but it is obvious that the size of the unit cube must be related to the grain size or the pore size of the body. The size of the unit cube and the chosen combination of tortuosity and constriction factor will together determine the permeability of a synthetic porous body. A dis-

cussion of the relationships between grain size, permeability, tortuosity and constriction factor, however, is beyond the scope of this paper.

ACKNOWLEDGMENT

The author wishes to thank the Amerada Petroleum Corp. and the Geophysical Research Corp. for permission to publish this paper, and E. E. Finklea for his assistance in obtaining and arranging the data that were used.

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DISCUSSION

By M. R. J. Wyllie, Gulf Research and Development Co., Pittsburgh, Pa., Member AIME.

This is a most interesting paper. It will undoubtedly be found particularly useful by those who are repelled by the purely mathematical definition of tortuosity offered in References 2 and 3 of the author. Personally, I believe that the constriction and tortuosity effects proposed by the writer to account for formation factor variations are essentially correct. It would be unfair, however, if I did not point out that Winsauer, Shearin, Masson and Williams[1] put forward last year a basically similar proposal. Fig. 1 of their paper should be compared with Fig. 1 of the writer's.

While I concur with the general conclusions of the writer, I am on principle unhappy about his use of the pore system of Fig. 2 to compute even semi-quantitative data. The system of Fig. 2 is basically anisotropic. Thus, while the resistivity across cube faces is always the same, that measured across cube diagonals, for example, will be different. A porous medium in which the pores are truly randomly disposed is electrically isotropic.

The writer, like all others before him, has failed to resolve the fundamental difficulty: to separate the measurable quantity, formation factor, into independently measurable components. It would seem that this can only be done on the basis of certain assumptions. If the free area of the medium is assumed constant, it is possible from the measured formation factor and porosity to calculate a fictitious average path length (tortuosity). This is the method of Wyllie and Rose and its object is to permit the Kozeny equation to be extended. If the average path length in the direction of current flow is considered to be equal to the overall length of the medium, a fictitious average porosity, less than the true porosity, can be calculated. This method was used for convenience by Garrels, Dreyer and Howland[2] when solving diffusion equations. In the present paper by making use of the measured formation factor and porosity, Owen can assume a tortuosity and find a constriction factor or vice versa. But he cannot independently measure either. It is true that Winsauer *et al.*[1] have claimed to measure tortuosity independently, but a more detailed analysis of their method will reveal that actually theirs is an ingenious method to measure formation factor. In this connection, a comparison of their method with that used and discussed by Schofield and Dakshinamurti[3] will be found to be helpful.

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AUTHOR'S REPLY TO MR. WYLLIE

Wyllie's comments on this paper are greatly appreciated, and certainly a synthetic pore system isotropic in all senses is to be desired. However, the writer feels that in choosing a single pore system identical, when desired, in its characteristics in the directions of its three coordinate axes, a system sufficiently close for present purposes to a truly isotropic system has been achieved. The purpose of this system, of course, is to represent to a first approximation, simply and in a systematic manner, the random pore system of actual porous bodies. The effects of constriction such as are obviously present in varying degrees in natural porous bodies are readily determinable for the chosen synthetic system, and it is shown that the magnitude of such effects can be large. The writer recognizes, of course, that new cube faces cut normal to the diagonals of the assumed unit cubes will not yield resistivities identical with those in the directions chosen, but insists that this, however, is a matter of no particular importance, as the axes of the synthetic body can always be chosen to align with those of the natural porous body it is to represent.

In regard to the paper by Winsauer, Shearin, Masson, and Williams, the writer feels that here the concept of constriction as an important factor in porous body resistivity was entirely missed. In Fig. 1 in the Winsauer, *et al.*, paper the apparent purpose is to show that there is some degree of tortuosity in the pore space between sand grains. The value of constriction involved in the figure is probably two or three, and it can be seen that by making the upper sand grains in the figure approach the lower ones the value of constriction can be increased enormously without appreciably modifying the tortuosity. That such a change in constriction will lead to a large increase in the resistivity of the porous body was not considered. The writer's present paper was given by personal communication in essentially its present form to Winsauer, Shearin, and Williams in August, 1950. The fact that Winsauer, *et al.*, made no reference to the concept of constriction as given them by the writer through this personal communication 18 months before publication of their paper may be taken to mean that they did not recognize the constriction concept as herein presented to be of importance in resistivity considerations. In the writer's judgment Winsauer, *et al.*, have not truly measured tortuosity in the experiments they have described.

Wyllie points out that the present paper does not show methods of measurement by which effects of tortuosity and constriction in an actual porous body can be independently determined. This is correct. However, it was shown that when assumptions are made limiting tortuosity to reasonable values, constriction in any actual case will be bracketed within rather narrow limits. The writer feels that the information thus obtained justifies the present attempt to represent actual porous bodies with a synthetic pore system of the type described. ★ ★ ★

POSSIBILITY OF CYCLING DEEP DEPLETED OIL RESERVOIRS AFTER COMPRESSION TO A SINGLE PHASE

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ABSTRACT

The compressing of gas into a partially depleted gas drive oil reservoir to bring the contents to a single phase miscible with gas is proposed as a process worthy of serious study. The compressed gas and vaporized oil would be recovered by cycling. This paper explores the possibility of recovering oil from reservoirs of 6,000 ft or more by this method.

INTRODUCTION

Many new methods for increasing the recovery of oil from reservoirs are under consideration in the various research laboratories. One method which should be considered for recovering oil from partially depleted gas drive fields is to compress gas into the reservoir until the contents become a single phase miscible with more gas. Natural gas then may be cycled through the reservoir to recover the oil. This procedure ideally will eliminate the capillary effects of the liquid in the porous media and should permit recoveries similar to those obtained in cycling operations, probably of the order of 80 per cent. This paper explores the information now available for the prediction of the performance of such a project and discusses the problems likely to be encountered in recovering oil by cycling.

For many years dry natural gas has been passed through oil reservoirs to recover natural gasoline which would vaporize from the oil. Recently a process of recovering more of the high boiling hydrocarbons has been described by employing high pressures at which the heavier hydrocarbons have a higher volatility.[16] Nevertheless, this reported method does not eliminate the differential nature of the vaporization process and capillary forces are still present in the reservoir. The process under discussion in this paper would minimize differential vaporization and would remove capillary forces which are responsible for low oil recoveries. Higher gas pressures are required to accomplish this removal of the miniscus, but it does not follow that more gas is required for oil recovery. The process is limited to reservoirs deep enough to permit the use of the required pressure — probably 6,000 ft and deeper.

[16]References given at end of paper.

Manuscript received in the Petroleum Branch office Aug. 20, 1951. Paper presented at the Fall Meeting of the Petroleum Branch in Oklahoma City, Okla., Oct. 3-5, 1951.

DESCRIPTION OF THE PROCESS

Briefly, the process is to compress natural gas into an oil reservoir which is partially depleted so that it has an oil saturation in the range of 40 to 60 per cent of the hydrocarbon pore space. The injected gas will pass through the channels formerly carrying gas to the wells to build up the pressure and dissolve in the oil phase. This injection will continue without production from the field until the reservoir reaches a single phase. If one were to select unique conditions such that the gas composition, the reservoir oil composition and the per cent saturation would bring the mixture in the reservoir to the critical temperature and pressure simultaneously the phase behavior accompanying injection is shown by Fig. 1.[6] The oil-gas mixture in the depleted reservoir has a critical temperature at C_1. Addition of natural gas to the mixture will give a new critical temperature for each addition. Mixture No. 3 is shown to have its critical temperature at the reservoir temperature and reservoir pressure at P_3, the critical pressure. Under ideal behavior, the entire reservoir would be at its critical temperature and pressure and the entire hydrocarbon content would be at a single phase.

If the reservoir content were a binary system of methane and a heavy constituent, it would be miscible with more methane. However, for complex mixtures the critical locus does not confine the two phase region, and the dew point curves of Fig. 1 occur above the critical locus. If fluid which was injected into the reservoir at the critical point were of the

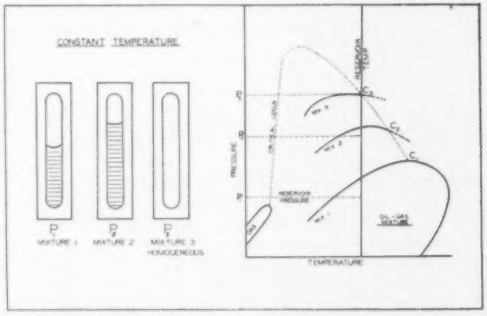

FIG. 1 — EFFECT OF ADDING GAS TO PARTIALLY DEPLETED CONSTANT VOLUME OIL RESERVOIR.

same composition as the reservoir fluid, obviously these fluids would be miscible. It is believed that injected fluid containing the more volatile and intermediate constituents without the less volatile constituents would also be miscible at the increased pressure resulting from injection of such gas. The injection of relatively pure methane could require considerably higher pressures before one reached a condition of complete miscibility.

In case only dry gas were available for injection and some liquid did precipitate at the front between the reservoir fluid and the displacing gas at pressures above the critical locus, it is quite possible that such liquid would revaporize in a differential manner and not seriously interfere with the displacing process. Such a process is more nearly like the differential process described[10] excepting that only a relatively small fraction of the reservoir fluid at the displacing front is involved.

The usual reservoir and gas mixture when compressed will likely cause the reservoir to become liquid full at single phase, Fig. 2A. Under this condition, the single phase liquid could be produced much as a virgin reservoir. This second production could be halted as gas/oil ratios increased and a gas phase was created which could be used as channels for a subsequent repressuring to a higher pressure at which a single phase miscible with gas could be attained.

Some reservoirs would reach a dew point upon injection of natural gas, Fig. 2B. This dew point mixture is miscible with natural gas at a slightly increased pressure and could be cycled.

Cycling of reservoirs which have been brought to a single phase by gas injection would be generally similar to current practice, except that penalties for allowing the reservoir pressure to drop would be more severe.

The process depends upon the ability to vaporize mixtures by compression of natural gas over crude oils. The phase relations of oil-gas mixtures will be considered to find the necessary pressures.

PHASE RELATIONS FOR COMPRESSION OF GAS OVER CRUDE OILS

Over 10 years have passed since the writer observed that a condensate from a vapor phase at 9,300 psi and 120°F has most of the properties of a crude oil, except the presence of asphalt.[14] In the school year 1941-42, students designed a plant to separate lubricating oil from asphaltic crude oils by

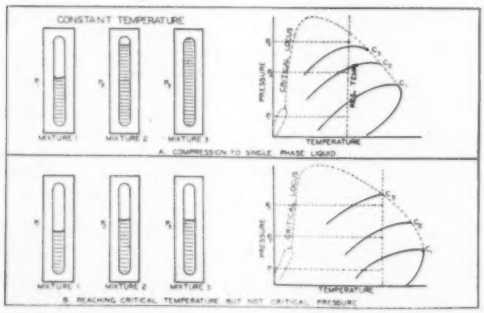

FIG. 2 — ALTERNATE POSSIBILITIES UPON GAS INJECTION.

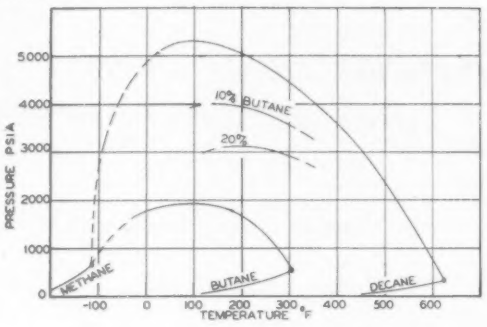

FIG. 3 — CRITICAL LOCUS FOR METHANE-BUTANE-DECANE SYSTEM.

fractional retrograde condensation from gas phases at moderate temperatures and pressures around 8,000-10,000 psia. It was evident that the pressure required for vaporization of heavy oils was related to the total composition of the mixture or in particular to the concentration of ethane, propane, butane, etc.

Several crude oil-natural gas systems have been investigated to indicate the pressures required to bring mixtures to a single phase miscible with gas. However, it is worthwhile to consider a simpler ternary system to develop the principles involved.

THE METHANE-BUTANE-DECANE SYSTEM

Sage, Lacey and co-workers[11,12,13] have studied the methane-butane-decane ternary system. Fig. 3 indicates the nature of the critical locus for the binary mixtures and the nature of the locus for some ternary mixtures. It may be seen that mixtures composed only of methane and decane may require compression to 5,000 psia to bring them to the critical pressure while the addition of butane to the mixture will lower the pressure for reaching the critical condition. Fig. 4 shows this lowering of the critical pressure by butane addition.

At any given pressure, the vaporization characteristics depend upon the degree of approach to the critical pressure, which in turn depends on the mixture composition. Fig. 5 shows the effect of butane concentration upon the ability of the vapor to carry decane. It may be seen that the effect of butane on the decane carrying capacity of methane is increasing with increased pressure.

Consider the compression at 280°F of a system composed of 14.3 mol per cent decane and 85.7 per cent methane. It will be in the two phase region until the pressure reaches 4,600 psia, the critical pressure, and above that pressure, it would be in the single phase region. If a mixture of 10 per cent decane, 20 per cent butane, and 70 per cent methane were compressed at 280°F, it would become a single phase at 3,000 psia. The addition of butane, or any intermediate constituent, lowers the critical pressure and the dew point pressure for the mixture.

Suppose the methane-decane mixture were present in a porous media at 4,000 psia and 280°F. It would be in the two phase region and capillary forces would be present. The use of natural gas to displace the mixture from the porous media would bring relative permeabilities into play, with gas flowing preferentially to the liquid. If the mixture had been com-

pressed to a pressure greater than 4,600 psia in the media prior to the injection of the displacing gas, capillary forces would be absent and the displacing gas could completely displace the methane-decane mixture from the media.

If the methane-butane (70-20-10) mixture had been in the media, it could have been displaced as a vapor at pressures just above 3,000 psia.

Information on the miscibility of natural gas with a crude oil-natural gas mixture which has been brought to the critical condition, such as in Fig. 1, may be gained from the ternary system. Fig. 5a taken from Reamer, Sage and Lacey[12] may be used to illustrate the problem and give a solution for the three component system. Consider a reservoir liquid at 1,000 psia of the composition indicated by point *A* (20 mol per cent methane, 36 per cent butane, and 44 per cent decane) to which is added gas of composition *B* (85 per cent methane, 15 per cent butane) with increasing pressure. At point *C* (70 per cent methane, 20 per cent butane, and 10 per cent decane) the total mixture would be at its critical point if the pressure were at 3,000 psia and could correspond to point *C* on Fig. 1. If more gas of composition *B* were added to the critical mixture, it would be miscible with the gas. However, should pure methane (point *D*) be added to this critical mixture *C* at 3,000 psia, the mixture would be in the two phase region along line *CD* until point *E* was reached. It may be seen that if the addition of methane to the critical mixture at *C* should have been accompanied by a pressure rise to around 3,250 psia, the new mixtures would not be in the two-phase region.

PHASE DIAGRAMS FOR COMPLEX MIXTURES

The author became convinced some 10 years ago that phase diagrams should be measured for complex hydrocarbon systems upon which vapor-liquid equilibria data were obtained. To that end phase diagrams were estimated for the systems

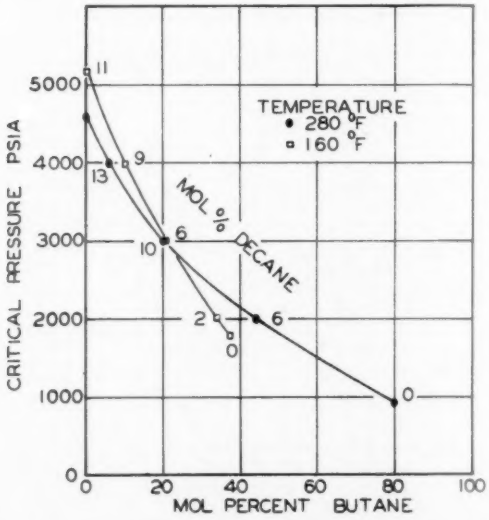

FIG. 4 — CRITICAL PRESSURES FOR METHANE-BUTANE-DECANE SYSTEM.

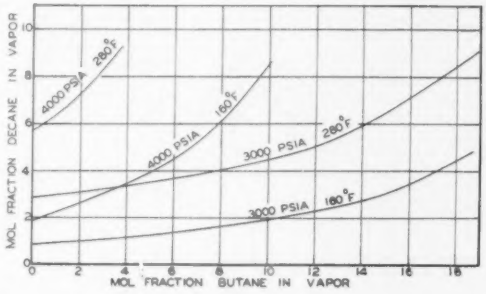

FIG. 5 — EFFECT OF BUTANE CONCENTRATION ON DECANE VAPORIZATION.

studied by Standing[15] and Roland.[16] The natural gas-crude oil mixtures employed are given on Table I along with the estimated pressures at which they become single phases. The phase behavior of many condensate systems has been determined. A few condensate systems are included in Table I.

The pressure at which a given mixture of natural gas and crude oil will reach a single phase is of prime importance in the proposed process. This pressure may be computed from equilibrium constants[16] by calculations which are rather involved and which require a careful analysis of the higher boiling constituents. The pressure may be determined experimentally in the laboratory. To give some idea of the single phase pressures and the influence of intermediate constituents, Fig. 6 has been prepared. The ratio of the methane concentration, mol fraction, to the combined concentration of ethane, propane and butane is plotted as a function of the single phase (dew point) pressure. It is known that the total composition of the system must be considered but this simplification may be some guide to the influence of the concentration of intermediate constituents.

Examination of the compositions in Table I is worthwhile from the standpoint of what causes a 9,300 psia dew point pressure for the crude oil-gas mixture[14] while the rich condensate *A* is at its dew point at 4,000 psia. There is a minor difference in the molecular weight of the heptanes and heavier constituents, 198 as compared to 172, but the major difference is in the concentration of constituents ethane through hexane. It seems quite likely that if the ethane through hexane concentrations or ratio to methane had been as high for the crude oil as for condensate *A*, the crude oil-gas mixture would have become a single phase below 5,000 psia.

EFFECT OF ASPHALT ON DEW POINTS

One of the problems to be faced when compressing natural gas over crude oils containing asphaltic constituents is whether these asphaltic constituents will vaporize. If they do not vaporize continuously with the other high boiling constituents, they will form a plastic solid phase in equilibrium with the gaseous phase. Thus, some of the pores in the porous media may be filled with this plastic solid.

Some indication of unusual dew point phenomena has been found by the writer when discussing the experiences of different laboratories. Generally the dew point is sharp, or slight

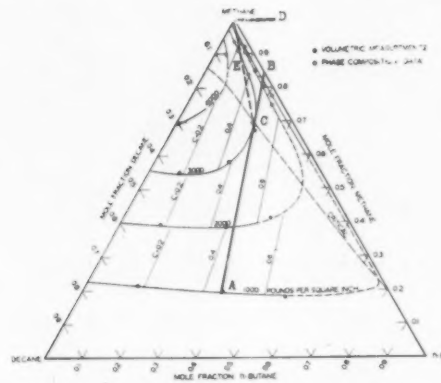

FIG. 5a — COMPOSITION OF COEXISTING PHASES IN METHANE-BUTANE-DECANE SYSTEM AT 280°F AFTER REAMER, SAGE AND LACEY[13] USED TO ILLUSTRATE MISCIBILITY OF GASES WITH CRITICAL MIXTURES.

Table I — Compositions of Complex Mixtures Mol Per Cent

	Crude oil-gas[14]	Crude oil-gas[15]	Paloma Condensate[8]	Condensate A[9]	Condensate B[3]	Condensate C[3]
carbon dioxide		0.42	0.77	0.45		
methane	81.11	75.86	71.92	64.38	80.68	73.81
ethane	3.91	3.46	8.28	7.36	5.73	6.37
propane	1.96	1.48	5.23	5.93	3.41	5.10
butanes	1.63	1.62	3.27	5.71	2.11	3.38
pentanes	1.11	5.22	1.62	3.09	0.95	2.25
hexanes	1.20	3.96	8.91	2.48	0.62	1.40
heptanes	9.08	7.98		10.60	6.50	7.69
sp. gr. C_7	.8268	.850	.798	.806	.823	.800
mol wt C_7	198.	199.	137.	172.	175.	137.
dew point pressure psia	9,300.	8,500.	4,650.	4 000.	8,000.	4,250.
temperature °F	200	170	235	260	220	210
ratio $\frac{C_1}{C_2\ C_3\ C_4}$	10.8	11.5	4.28	3.39	7.2	4.97
gas/oil ratio	4,700	3,660	6,777	3,340	8,520	6,280

decreases in pressure cause large quantities of liquid to form by retrograde condensation as shown on Fig. 7 for condensate *A*. However, for some mixtures containing small amounts of high boiling constituents, the first unit of liquid formation requires a relatively large pressure drop as shown by curve *B*, Fig. 7. The presence of asphaltic constituents which would resist vaporizations would cause a similar behavior near the dew point since the dew point no longer would exist as a definite point capable of determination. Curve *C* represents the author's concept of the effect of asphalt in the absence of any data. Some asphaltic constituents may vaporize, but the "pseudo dew point," point *D* for mixture *C* on Fig. 7, should be considered as the top pressure for compression of a reservoir containing crude oil with an asphalt content which would give a condensation curve similar to curve *C*.

RESERVOIR PROBLEMS

There are many problems of phase behavior and fluid flow which must be considered for the compression of natural gas into a partially depleted crude oil reservoir to bring it to a single phase. The pressures required may be considerably higher than those originally present in the reservoir. How high a pressure can be used in a reservoir? The best answer known by the writer is that pressure just below the well pressure which parts or fractures the formation. No accurate figure for various areas is available, but it is likely to be from 0.8 to 1.2 psi per foot of depth. Thus, a 6,000 ft reservoir would likely stand 4,800 psi pressure and this pressure could be sufficient to vaporize some crude oils if a gas rich in intermediate constituents were used. The process should be considered for reservoirs at depths of about 6,000 ft and more. Reservoirs at 10,000 ft would give a high degree of latitude in safety and ability to vaporize crude oils.

One of the main problems is to introduce the gas so that it will go into solution throughout the reservoir. For a partially depleted reservoir with high producing gas/oil ratios, the injected gas should pass through the porous media without displacing much liquid except near the injection well. With pressure increases in the reservoir, the liquid will swell in volume and decrease the gas permeability. If the liquid percentage reaches some 90 per cent, no more gas may travel through the porous media. If subsequent compression does not bring the mixture to a single phase miscible with natural gas, it will be necessary to produce some of the liquid from the reservoir to give more room for the gas. A second injection would permit the entire reservoir to be raised to a critical pressure or a dew point.

At this point, it is interesting to note that the increase in pressure toward a critical pressure does not necessarily mean the liquid phase is swelling. For a constant composition system at its critical temperature, compression to the critical pressure will not increase the percentage liquid beyond some 50-55 per cent by volume. With changing composition at constant volume, there is no reason to expect high liquid saturations before reaching a critical pressure. This means that gas movement may continue throughout the reservoir as the critical pressure or dew point is approached. The amount of oil still in a reservoir and injection gas composition can become very important factors in the percentage gas phase in the reservoir and hence on gas movement throughout the reservoir.

There will be strata in the reservoir which will contain a higher saturation with oil than others. These strata will not

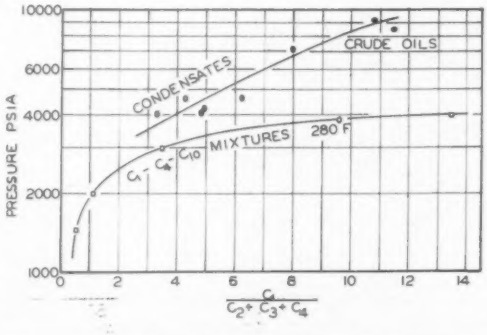

FIG. 6 — EFFECT OF INTERMEDIATE CONSTITUENTS ON PRESSURE FOR SINGLE PHASE.

take as much gas, and hence they will not be completely vaporized upon compression even though the oil in other zones might be completely vaporized.

Diffusion time for the gas to go into solution in oil with which it is in contact will be no problem for uniform porous media into which gas is flowing, but if it is expected that gas will travel either horizontally or vertically through liquid filled sand, diffusion will take far too long a time to put gas into solution.

To the extent that these items interfere with the ideal compression of the entire contents of a reservoir to a single phase, there will likely be differential processes which will increase the amount of gas injection required to recover the oil.

When reservoir pressures are employed which are considerably in excess of those originally in the reservoir, the completion of wells and corrosion of casing or fittings become of concern. Any abandoned wells in the reservoir should be plugged in a manner to make certain that leaks will not occur.

APPLICATION OF METHOD TO A FIELD BY STUDENTS

Students in petroleum production engineering at the University of Michigan[2,3] were given the problem of designing a plant and making a cost estimate for compressing gas into a field followed by cycling to recover the crude oil. The characteristics of the oil and general data for the field correspond to the North Lindsay Reservoir, McClain County, Oklahoma.[1,3,4] Since much of the data on the geology of the reservoir and other details were not available, assumptions were made. Thus, the field will be described as Field "A" as the information is in part hypothetical and the results should not be considered as applying to a particular field. The results of the study are presented as a basis for discussion of the problem and decisions to be made on such a project.

Both groups assumed that they could purchase high pressure gas of the following composition — methane 86.1 mol per cent, ethane 7.5, propane 4.2, butanes 1.26 and pentanes plus 0.94. A three stage operation is proposed. The first stage consists of gas injection without production from the field. The second stage consists of cycling at substantially constant pressure to recover the crude oil. The third stage is the production of gas for pipe line sale. The two groups of students made independent studies based on different compositions for the reservoir fluid and using different types of plants. Some of the results of these calculations are given in Table II.

Table II — Summary of Data and Results for Student Design Problems: Data on Field A

	Group I*	Group II**
Depth, ft	10,700	10,700
Discovery pressure, psia	4,600	4,925
Reservoir Temp. °F	189	189
Initial Formation Volume Factor	2.2	3.073
Initial Solubility, cu ft/bbl	2,180	3,694
Reservoir Volume, MM bbl	24.	24.
Oil Production, MM bbl	2.4	2.4
Gas Production, billion cu ft	10.0	10.0
Current Producing GOR cu ft/bbl	18,000	18,000
CALCULATED RESULTS		
Current Equalized Reservoir Pressure, psia	1,440.	2,400.
Stock Tank Crude Oil still in Reservoir, MM bbl	8.7	5.48
Minimum Pressure for Single Phase in Reservoir, psi	5,300	4,800
Pressure during Cycling, psi	6,000	5,300
Gas Required, billion cu ft	27.5	21.
Time to Inject Gas, years	1	1.5
Time to Cycle Field, years	3.25	9.5
Plant Capacity, MMcf/D	47.	17.
Oil Production in Process, MM bbl	7.0	4.4
Gas Purchased per bbl oil Recovered cu ft/bbl	3,950	4,800

*Based on analysis of reservoir fluid in Reference 1.
**Based on analysis of reservoir fluid in Reference 3.

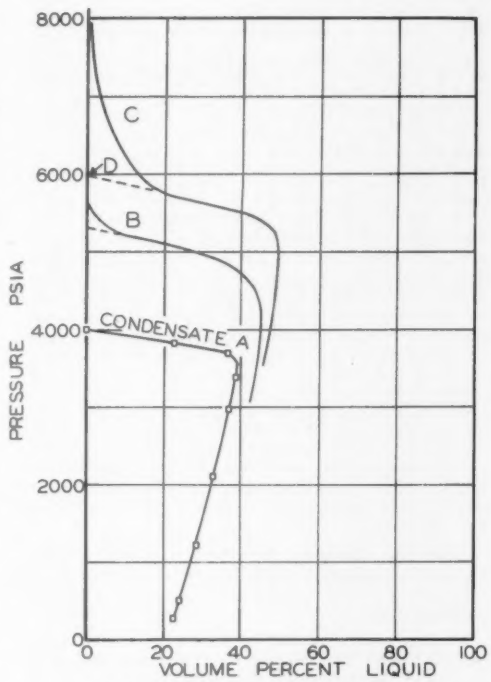

FIG. 7 — EFFECT OF ASPHALT ON DEW POINT.

Group I

This group based their calculations on the published data of crude oil behavior for the discovery well.[1] They computed that the reservoir would become single phase at 5,300 psi and be below its critical temperature at 189°F. At 6,000 psi they estimated that the displacing gas would become miscible with the reservoir fluid.

During the period of crude oil production, oil-gas separators, cooling equipment and compressors comprised the plant, since the wet gas was returned to the reservoir. Separators at 3,000, 1,000, 330, 100 and 30 psi were used, with 2,750 gas compression horsepower.

After substantially all the oil had been recovered, the wet gas in the field was produced for pipe line sale through 1,000 psi absorption equipment. The total plant cost was estimated as under three million dollars.

Group II

This group used the well fluid analysis published by engineers of the U. S. Bureau of Mines.[3] They estimated that gas compression would bring the reservoir to a dew point at 4,800

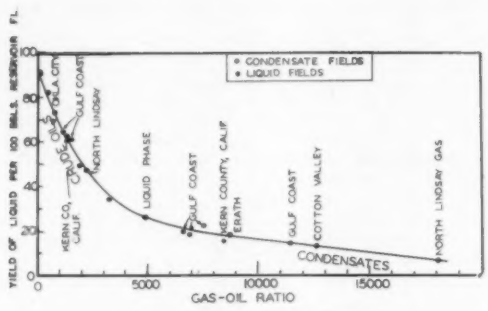

FIG. 8 — COMPARISON OF YIELDS.

psi and cycled at 5,300 psi. They recovered the natural gasoline and LPG during a normal cycling operation with absorbers operating at 2,800, 1,400, 800, 300 and 75 psi. The reservoir was full of dry gas at the end of the cycling. The plant cost for this operation was calculated to be around two million dollars.

Insufficient information was available to make studies of the effect of varying permeabilities on lack of reservoir equilibrium or premature break-through of cycling gas over the displaced fluid.

Needless to say, the costs of production in these idealistic calculations are low, but they constituted only one-fourth to one-half of the total income from product sales.

GAS REQUIREMENTS AND VALUE OF LPG CONSTITUENTS

A mixture which is at its critical temperature and at or above its critical pressure contains the greatest amount of crude oil per unit of gas in a state miscible with a gas phase. Fig. 8 shows the gas/oil ratio from separator operation at 200-500 psi for crude oils and condensates as a function of the yield of liquid per 100 bbl of reservoir fluid. Those mixtures between 3,000 and 5,000 cu ft/bbl are close to the critical temperature and represent the richest condensates. Crude oils may be brought to this state by injection of the proper composition gas. Added gas is required during cycling to maintain the reservoir pressure, and some gas will mix with the crude oil not recovered, bringing the total gas to 6,000-10,000 cu ft/bbl of oil recovered. This gas is available for reuse or resale at the end of the project, except for plant fuel requirements.

No study has been made of the value of LPG in reducing the maximum pressure required to vaporize a given oil. In some cases the enriching of injection gas may be necessary to obtain a single phase within the pressure range permissible in the reservoir. In other cases, it may be cheaper to use less enriched gas because of the lower pressure required. Consider the use of an enriched gas for vaporizing crude oil studied by Roland[4] in place of the gas employed. The ratio of the volume of ethane through hexane fractions to the heptanes plus is 0.4 for the single phase mixture. In other words, there is about 0.4 bbl of LPG and light natural gasoline per bbl of crude oil in the vaporized mixture at 9,500 psi. On the other hand, consider condensate *A*. This mixture contains one bbl of ethane through hexane per bbl of heptanes plus for the vapor at 4,000 psi. It is estimated that if the crude oil mixture would have had one bbl of intermediate constituents ethane through hexane per bbl of crude oil, it would have become a single phase at around 5,000 psi instead of at 9,500 psi. The 0.6 bbl of intermediate constituents per bbl of crude oil no doubt would reduce the pressure for bringing the reservoir to a single phase to around one-half the previous value.

Following these concepts, it would seem that a stock-pile of natural gas and intermediate hydrocarbons ethane through butane or pentane might be accumulated and used in succeeding reservoirs over and over again. The investment per bbl of oil recovered in such a program requiring a very rich gas might be as follows:

8,000 cu ft gas @ 6 cents	= $ .48
0.6 bbl LPG @ $1.68	= 1.01
	$1.49

If the investment were recovered in six years on the average, the cost at four per cent per year would be 38 cents per bbl of oil recovered for the use of the compression fluid.

CONCLUSIONS

Further study of the proposed process is recommended. Laboratory measurements should be made of the pressures required to bring given crude oils and various enriched gases to a single phase miscible with natural gas. At the present time, the author concludes that:

1. The proposed process is feasible for reservoirs of 6,000 ft and deeper which have characteristics which would permit cycling for condensate recovery.
2. It is possible to bring most crude oils of 35° API and higher to a single phase by the use of natural gas enriched with LPG. The asphaltic constituents present may not vaporize but become a plastic solid.
3. The compression of gas over oil to bring it to a single phase miscible with gas requires less gas circulation through the reservoir to recover a barrel of oil and should give higher recoveries than differential vaporization processes.
4. Problems of contacting the gas with the oil to realize the ideal phase behavior in the reservoir may be serious.
5. Details economic studies on deep reservoirs are likely to show the process to be the most economical secondary recovery process for some of these reservoirs.

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DISCUSSION

By C. S. Matthews and J. G. Roof, Shell Oil Co., Houston, Tex., Members AIME.

Some of the confusion which has arisen concerning the concepts in this paper might have been avoided if, since the systems under consideration are essentially isothermal, the discussion had been referred to pressure-composition diagrams rather than the pressure-temperature diagrams shown in Figs. 1 and 2. Although a pertinent pressure-composition diagram was published at least as early as 1945 (Reference 8 of the paper), Allen[1] recently presented more detailed diagrams, one of which serves as the basis of Fig. A. From this diagram it is readily seen that the reservoir pressure must be increased to p_A to insure miscibility of reservoir fluid with separator gas during displacement by that gas. If the injected gas is rich in intermediate components, it is probable that the difference between p_A and the critical pressure will be reduced from that shown in Fig. A. However, the important idea is that from a diagram of this type, obtained for the crude oil and the proposed injection gas, one can readily recognize the minimum pressure required for miscibility

That Katz is aware of this fact is indicated by his second paragraph under "Description of the Process." However, confusion arises when in a subsequent section the statement is made: "The pressure at which a given mixture of natural gas and crude oil will reach a single phase is of prime importance in the proposed process." It is easily seen from Fig. A that the single-phase pressure for any given composition is of no importance. It is the position of the cricondenbar, p_A, which is of importance generally. In another section Katz makes the general statement, "This dew-point mixture is miscible with natural gas at a slightly increased pressure and could be cycled." The data of Allen[1] show that "slightly increased pressure" may mean thousands of pounds per square inch.

It is clear that there is the need for a study of the significance of pressure-composition diagrams for given systems. Consider a partially depleted constant volume reservoir into which gas is injected until a dew point is reached. This dew-point gas is not necessarily miscible with additional gas during subsequent cycling at constant pressure. It is the cricondenbar rather than the dew-point pressure which determines the minimum pressure for achieving complete miscibility. Therefore, it is questioned whether the data in Fig. 6 and Table I have any bearing on the problem. The dew point pressure so reported tells nothing about the pressure required for miscibility. The data presented by Allen[1] give significant informa-

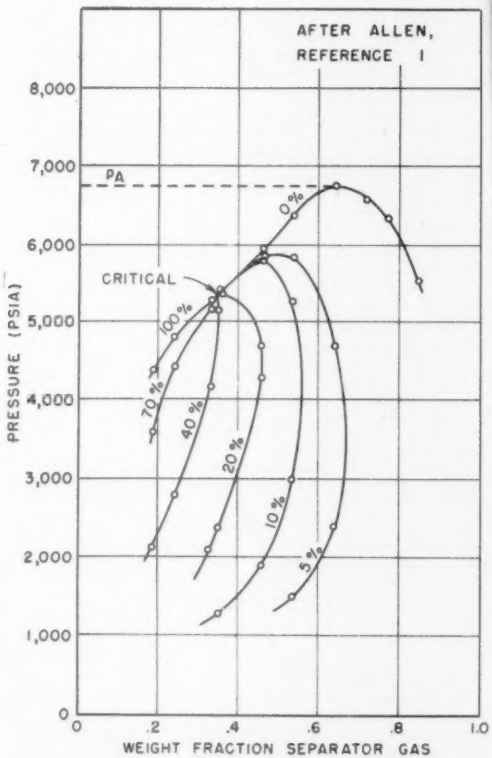

FIG. A — PRESSURE-COMPOSITION DIAGRAM AT 251°F, GULF COAST CONDENSATE FIELD.

tion in this regard. Allen's data indicate that the cricondenbar (or minimum pressure for miscibility) will generally be not lower than 7,000 psi for mixtures of high-gravity black oil and separator gas. Only for condensate liquids (as illustrated in Fig. A) is the difference between the cricondenbar and the critical pressure of a low order of magnitude.

The operation proposed in this paper differs from that discussed by Whorton and Kieschnick in 1951 (Reference 16) only in that it is now proposed to operate at all times in the one-phase region which, for the type of systems under consideration, means operating at or above the cricondenbar, p_{AA}.

REFERENCE

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AUTHOR'S REPLY TO MESSRS. MATTHEWS AND ROOF

The author agrees heartily that the paper by Allen is most helpful in presenting data which answer questions raised in the paper. Allen's paper was not available until some six months after the paper under discussion was prepared and presented. It should be pointed out that Allen presented other systems in figures similar to Fig. A, two of which show the dew points rising only about 200 and 500 psi respectively above the critical pressure while two other systems have rises greater than that shown in Fig. A.

Matthews and Roof apparently did not understand the main point to the paper, *i.e.*, the value of bringing the entire reservoir to a single phase *before* displacing the contents of the reservoir. Their point that the pressure at which the returned gas is miscible with such a single phase may be considerably higher than the single phase pressure is well taken. If they had data similar to that published by Allen, presentation of the facts at the time this paper was presented would seem to have constituted a more informative discussion. Granted that complete miscibility of returned gas with a single phase reservoir fluid may require too high a pressure to be practical for some reservoirs, there may be many for which the pressures are not above practical limits. In those cases, the reduction in gas requirement for high oil recovery is a factor of two or three less than passing gas through the reservoir at a pressure some 80 per cent of that required to bring the reservoir to a single phase.

Consider the case of a reservoir brought to a single phase at 6,500 psi but with a pressure requirement of 8,500 psi for complete miscibility of the reservoir contents with the returned gas. Consider further that it is not practical to cycle at pressures above 7,000 psi and so cycling is started at this mean reservoir pressure. Only at the interface between the single phase reservoir fluid and the returned gas will precipitation occur. The gas at this interface would likely attain a composition such that further precipitation would be minimized as cycling progresses. The condensate formed would then be recovered by the returned gas to the extent that the differential process described in Reference 16 is sufficient for such recovery.

It should be mentioned that this paper and discussion has the same significance for cycling rich condensate reservoirs as for recovery of crude oils. Matthews and Roof are saying that it may be necessary to cycle such a reservoir at a 1,000 psi or more above the dew point. The emphasis of my paper is something generally recognized for condensate reservoirs, *i.e.*, it is a much more efficient operation to cycle at or above the dew point pressure than at some 80 per cent of the dew point (single phase) pressure. ★ ★ ★

THE STRATAFLOW PROCESS: A RECENT DEVELOPMENT IN LOCATING WATER ENTRY IN WELLS

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ABSTRACT

The Strataflow process for locating water entry in producing wells is now available. This method as now practiced utilizes the fact that fluids of different salinities have different electrical resistivities. By introducing into the well a fluid of a markedly different salinity than that of the fluid being produced, a pronounced resistivity change will occur at the point of entry. By running a Strataflow survey the points of major and minor water entry may be interpreted from changes in the resistivity of fluid in the hole.

Strataflow results are obtained with the well operating under almost normal producing conditions, and are a logical primary step in any workover program, having as its purpose shutting off of the water.

INTRODUCTION

Water production is a serious problem in many producing oil wells. It certainly increases lifting costs and in some cases presents a disposal problem. It often aggravates corrosion problems and can even endanger oil production. With accurate information to guide an effective workover program, many marginal wells could be restored to profitable production.

The shortcomings of previous methods of water entry location were recognized. The Strataflow process is the result of several years of development and field testing directed toward overcoming these limitations. It represents the continued development of a process reported by Silverman and Brown.[1] The earlier work established the basic soundness of fresh-to-salt water resistivity contrast in delineating zones of water entry, but its application was limited by the difficulty of maintaining static balance of the well during preparation for the test. A more serious deterrent to its use, however, was its unadaptability to existing well logging service equipment and field operating methods.

STRATAFLOW PRINCIPLE

The general principle of the new method involves, first, conditioning the well by displacing the fluid in the bore of the well adjacent to the zone to be tested by a conditioning fluid which is miscible with the formation fluid. This displacement is carried out without interruption of the well production. The conditioning fluid must have some measurable physical, chemical, nuclear, or electrical property which is distinctive from that of the formation fluid. As the well continues to produce, formation liquid entering the well bore dilutes the conditioning fluid so that zones of entry may be determined by making a log of the property undergoing change. This general principle may be applied to indicate zones of either water or oil entry by suitable selection of conditioning fluid and proper logging equipment.

The Strataflow process, as it is currently practiced for water entry location, uses fresh water as the conditioning fluid and depends for its operation upon the marked difference of electrical resistivity between this fresh water and the salty water produced by the formations. If possible, any necessary modifications of the well equipment are made a week or so before the test. The well is then returned to normal production. On the day the test is to be carried out, the conditioning water is landed at the bottom of the well and the test is made without interrupting production except for a brief period required for the conditioning water to consolidate into a continuous column extending to a point well above the test section. With this general description of the process in mind, a more detailed step-by-step description of the process will be clearer.

PRELIMINARY PREPARATION OF WELL

The Strataflow survey, as it is currently practiced for water entry location, is applicable only to pumping wells. Since the required electrical measurements are made by a special

[1]References given at end of paper.

Manuscript received in the office of the Petroleum Branch Feb. 8, 1952. Paper presented at the Annual Meeting of the AIME in New York City, Feb. 18-21, 1952.

fluid resistivity measuring electrode lowered down the well annulus, the tubing head is removed and the tubing string hung on a clamp in order to make the annulus accessible, unless the well is already equipped with an offset tubing head, particularly designed to admit an instrument into the annulus. Such an offset head is required on any well that might occasionally flow.

The electrode is one inch in diameter and can be run in any well in which the inside diameter of the casing exceeds the diameter of the tubing collar by at least one and one-half in. This means that in wells with 5½-in. casing and 2½-in. EUE tubing, it is necessary to change to a 2-in. tubing string prior to the test. Since the operation of the process is such that zones of water entry can be established only in sections of the well in which the conditioning water can be landed, it is desirable to set the pump inlet as low as possible. This sometimes makes it necessary to pull the tubing and replace the mud or gas anchor with a short perforated nipple. Below the pump inlet only aggregate production of water can be determined. This is done in a separate step in the testing procedure.

A careful check for tubing leaks should be made and any leaks detected should be corrected during the well preparation. This is necessary since the method would detect salt water entering the annulus from a tubing leak equally as well as that entering from the formation. The well is then returned to production and, if possible, operated continuously up to the time of the test. Several days' or a week's operation is desirable to insure that all formations are producing their normal fluids.

PURGING AND CONDITIONING

A supply of fresh water adequate for the test is provided by the well operator. A portable stock tank is used for storage if water is not available on location. A 100-bbl tank is adequate for most well testing. It is desirable to have a resistivity contrast between the conditioning water and that produced by the formation of at least four to one. In the case of wells producing brackish or comparatively fresh water, satisfactory Strataflow tests have been made using a conditioning water of lower resistance than that of the formation water. This can be prepared by adding salt to the water produced by the well.

On the day preceding the test a stream of fresh water is started into the casing at the well head and continued until the time of the actual test. The rate of injection is adjusted at approximately one-half the rate of total oil and water production of the well. This rate, however, is not critical, and supervision is not required to maintain it constant.

The circulation of water in this manner through the well annulus serves to purge the casing and standing oil column of water-soluble electrolytes and insures that the water landing at the bottom just prior to the test will have the maximum possible electrical resistance. The water continuously in transit through the oil column serves as a reservoir to supply the conditioning water required for the test.

On the day of the test service equipment is set up on the well, which is continued on pump until the fluid resistivity measuring electrode is run down the annulus to the bottom of the hole. The location of the pump inlet should be checked by observation of the sharp resistivity contrast at the oil-water interface, which always stabilizes at the pump inlet.

The injection of fresh water is then stopped, and the well is shut in temporarily to permit conditioning water, after falling through the oil, to consolidate in the annulus and form a continuous column from the pump inlet upward and beyond. The time required for this waiting period is difficult to estimate, but the progress of the water accumulation may be followed by scanning the well bore with the logging electrode. Twenty to thirty minutes is a typical example. During this interval the formation continues to produce so that the lower section of the column is progressively contaminated by salt water from the formation. A preliminary log of the fluid resistivity in the hole is made prior to the test to ascertain the resistance and the quantity of fresh water standing above the zone to be surveyed.

THE STRATAFLOW TEST

As soon as fresh water has accumulated to a point well above the top of the zone of interest, the "drawdown" step of the test is started by returning the well to production. Fresh water injection may also be resumed, as the input rate of fresh water into the annulus serves as an effective means of controlling the rate of production from the formation. For example, if fresh water is admitted at 30 per cent of the total production rate, the well will stabilize with 70 per cent of the fluid delivered to the surface being produced by the formation. By adjusting the rate of fresh-water input, the operator has a positive and convenient means of controlling the formation production. The injected water also replenishes the conditioning water in the standing column and prolongs the period over which the well test can be run.

Additional water injection may be omitted if control of formation producing rate is not necessary, and if the supply of water in the consolidated water column is large enough to carry out the test.

As the well is produced, the resistivity electrode is run in the annulus to produce a log of the resistivity of the fluid mixture in the zone under test. Successive records are made at frequent intervals so the operator can study the resistivity pattern as it develops. The logging speed is not critical, and experience has shown that there is a little tendency toward distortion of the pattern due to movement of the electrode.

Since the pump inlet is near the bottom of the hole, the movement of all water in the fluid column is downward. The high-resistance conditioning water, in passing formations producing salt water, has its resistance lowered. As the well production stabilizes, the downward flow of the column of fresh water and the flow of formation water into the column, both approach stable values. The change in resistivity across any producing horizon therefore reaches a value dependent upon the rate of formation production. In contrast, the fluid resistivity in the liquid column remains unchanged through sections of the bore hole where no salt water production occurs. This resistivity pattern is characteristic of the water productivity of the well formations.

When the characteristic resistivity pattern has developed, it is stable and can be repeated as long as production is continued and a supply of fresh water is available in the standing column above the zone of test. The way in which this pattern develops from the initial fluid-resistivity record varies with the method of well treatment but more specifically with the water-producing capabilities of the formations. In wells having a high productivity index, the preliminary log of this resistivity run just prior to the drawdown often shows all of the significant features of the final water productivity profile, and the fully stable pattern is developed in a few minutes of testing.

In most other wells, significant features, particularly in the upper sections

of the hole, may be indicated in the first few minutes of testing, but 15 to 30 minutes are required to develop a stable pattern. The test should be extended considerably beyond this time to insure that each stratum has reached producing equilibrium.

The water resistivity pattern developed by this drawdown step is capable of showing water-entry zones only down to the pump inlet. Wells having bottom water usually show a sharp resistivity drop at the pump inlet but this alone is not a diagnostic feature. Bottom water can be more positively indicated in an additional step of the test procedure, the "buildup." Water injection is stopped, and pumping is discontinued. All fluids produced now move up the hole. Bottom water is indicated by an upward movement of the sharp resistivity change originally occurring at the pump inlet. The initial rate of this movement permits an estimate of the rate of bottom water production.

It is advisable to make several drawdown and buildup tests during the course of each Strataflow survey. A brief buildup should be made early, perhaps before the final resistivity pattern is fully developed. Knowledge of bottom water from such a buildup is helpful in planning the remainder of the test.

STRATAFLOW RESULTS

The Strataflow method of water-entry location has recently been made available to the industry as a commercial well service. A workover done on Continental Oil Co. No. 4 B. B. Ainsworth in the Geneseo Field, Rice County, Kansas, is of particular interest since it was done in such a way as to test the accuracy of the interpretation of a Strataflow survey for water entry. The daily production of the well prior to the survey was about 60 bbl of oil and 200 bbl of water.

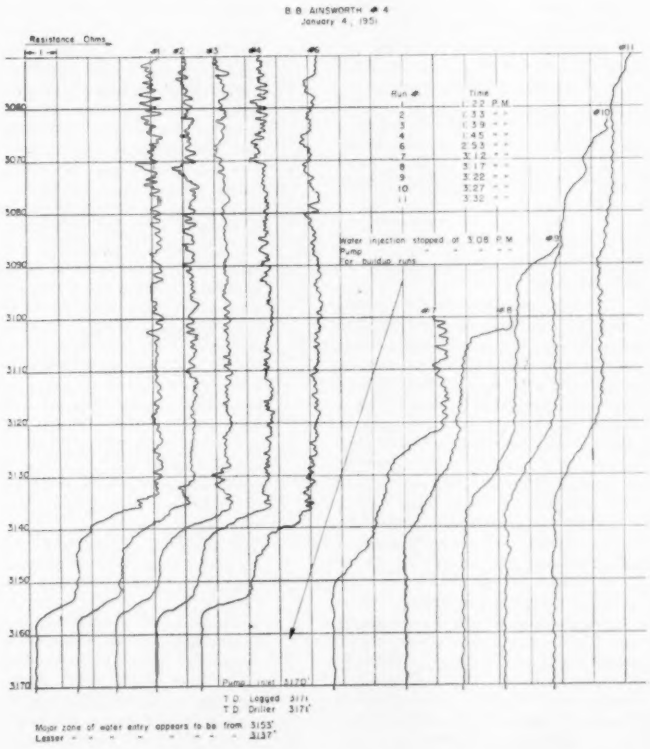

FIG. 1 — STRATAFLOW TEST, CONTINENTAL OIL CO. B. B. AINSWORTH NO. 4, JAN. 4, 1951.

Table I

Zone	Strataflow Interpretation
Above 3,136	No water entry
3,136 - 3,141	Water entry
3,141 - 3,153	Minor entry
3,153 - 3,157	Major water entry
3,157 - TD	No entry

The Strataflow survey was made in the manner that has been described. Several of the resistivity profiles obtained during the testing procedure are shown in Fig. 1. Individual profiles have been offset on the resistivity scale for the sake of clarity of presentation. Keeping in mind that zones in which no water is produced show a constant fluid resistivity and that sections showing changes of resistivity are indicative of zones of water entry, the interpretation shown in Table I becomes clearly evident.

The entry at 3,153 - 3,157 ft is considered more prolific than that at 3,136-3,141, since a proportionately greater amount of salt is required to make a given change in fluid resistivity at high salt concentration than at lower concentrations.

In testing the accuracy of the above interpretation, the well was cemented to the casing seat and then progressively redrilled through the producing horizon with periodic production tests made by swabbing. The results of these tests are shown in Table II. It is evident that no water is produced above 3,125. The water produced during four hours of swabbing at 3,131 was progressively decreasing and it appears that any water produced at this level was minor. The top of the water indicated by the Strataflow survey was 3,136.

The hole was then plugged back a second time with 30 sacks of cement. Hole was made to 3,095 ft when 300 ft of oil stood in the hole. At 3,112 ft oil was swabbed at 17 bbl per hour with no water. This substantiated the first plugback test at 3,111 ft, and the well was completed at this total depth. A 24-hour production on pump gave 336 B/D of oil with no water.

STRATAFLOW ADVANTAGES

An important advantage of the Strataflow method is that the record is made with the well operating under conditions almost identical to those which exist in normal production of the well. In the case of wells having a moderate

to low productivity index, it is doubtful if other fluid-entry methods produce the well to an extent sufficient to develop the characteristic production of each formation. In the Strataflow procedure, except for the temporary shutdown for water consolidation, the well is produced continuously prior to and during the test, and at no time is the well likely to approach static equilibrium. There is, therefore, little danger of low pressure formations being flooded by foreign fluids. Each formation, whether water- or oil-producing, produces its normal fluid prior to and throughout the full test period.

The Strataflow method of water-entry location is dependable, easy to interpret, widely applicable and economically practical. This is borne out by the following features, many of which are unique among methods of water-entry location.

The survey provides a continuous log which clearly indicates those zones from which water is entering the bore hole. Quantitative interpretation of the log is possible by reference to the per cent salt calibration of the electrode.

The method can be applied to any ordinary type of pumping well, regardless of the total production rate and the per cent water production. This includes wells producing hydrogen sulfide and those completed in limestone or dolomitic formations.

Operation of the electrode in the annulus yields a saving in cost. This is based on the fact that in wells where no mud anchor is normally used, and in which the tubing is of a size small enough to afford adequate electrode clearance in the annulus, there is no need to pull and rerun the tubing and rod strings. In these cases all that is required is to remove the normal wellhead seal and lower the tubing string sufficiently to set the pump inlet close to bottom.

It is not necessary to have a pulling unit stand by during the survey. Conducting of the actual well test is carried out with the use of Strataflow equipment only, and the only pulling unit time required is that necessary to prepare for the test and to return the well to its normal condition after the test. The survey can usually be conducted in a period of 24 hours with about eight to ten hours working time.

In conclusion, it may be said that the Strataflow survey is a logical investigative step to be taken on any well upon which a workover to shut off the water is contemplated. By combining water-entry location service with oil well cementing facilities, it is possible to undertake the broad problem of finding and shutting off the water.

Table II

Depth Drilled	Fluid Swabbed in BBl per Hour: First Plugback Oil	First Plugback Water	Second Plugback Oil	Second Plugback Water
3,100	6	—		
3,105	12	—	6	—
3,111	17	—		
3,112			17[e]	
3,115	17			
3,120	17	¼[a]		
3,125[b]				
3,131	18[c] 18[c]	11 7[d]		
3,137	20	26		
3,145	12	21		

a. Water disappeared after 16 hours of swabbing.
b. At 3,125 ft, 2,200 ft of fluid stood in the hole. No water was recovered from bailer run to bottom.
c. Results of two separate 2-hour swab tests.
d. Hourly water production rate decreased during the test.
e. New plugback TD.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the Continental Oil Co. for granting permission to publish results of their testing during the workover of the B. B. Ainsworth well.

REFERENCES

1. Silverman, D., and Brown, A. R.: "Location of Points of Water Entry in Oil Wells," *Trans.* AIME, (1948) **174**, 286.

DISCUSSION

By J. T. Gary, Continental Oil Co., Wichita, Kans., Member AIME.

The Strataflow process for locating water entry in wells appears to be an improvement over previous methods and may develop into a tool of extreme importance, especially for use in Kansas where the control of water production is of vital concern. The authors' paper should be considered as a progress report as much remains to be done in further developing the process and it is felt that additional uses for the tool will be developed. The authors have presented an accurate account of the results of the survey run of the B. B. Ainsworth well No. 4.

One limitation to the Strataflow process, which the authors did not mention, was found when a survey was run on another well in the Genesco Field. In this particular well, the hole was deepened in the Arbuckle below a former plug back depth for the express purpose of determining whether any water-free oil zones existed below an upper water zone which had been plugged off. The Strataflow survey did not pick up any zone of water entry except a high volume zone at the bottom. Since tests made while deepening and also electric log interpretation indicated the presence of minor water zones, it is thought that the high volume flow from the bottom zone restricted the flow from these minor zones to the extent that the instrument was unable to locate them. Possibly these minor zones could have been located had several Strataflow surveys been run as the hole was deepened, or at least one survey made before the bottom zone was penetrated.

AUTHORS' REPLY TO MR. GARY

As a general rule Strataflow surveys are particularly indicative of water entry from upper zones. However, there are several possible explanations for this well's failing to show water above the initial plugback depth after being deepened.

1. The water production could have been leakage around the plug.
2. The reservoir may have vertical permeability through fissures or, more particularly, in limestones through solution cavities. A shortened path, opened by the deepening of the well would completely bypass the water flow to the upper zone.
3. It is possible that the upper zone had formation pressure which was abormally low compared to that of the lower horizon. In this case there would be a tendency for the upper zone to "take" rather than produce water until the hydraulic head associated with the lower horizon was drawn down to a low value. Since this was one condition that was anticipated, clues indicating its occurrence were looked for in the experimental and developmental work on the process. The first 30 wells surveyed were examined in considerable detail with many of the surveys repeated under varying hydraulic conditions. In this work there was no evidence of "low pressure horizons."
4. It is possible that a mistake could have been made in the well conditioning. For example, if the fresh conditioning water flow were set in excess of the production, on a weight basis, the well would become overbalanced with the excess fresh water being taken by the formations. On the actual test the well might not be produced sufficiently to initiate formation water production from the less productive zones. ★ ★ ★

Petroleum Branch Affairs . . . as interpreted by JOE B. ALFORD Executive Secretary, Petroleum Branch

Managing an organization like the Petroleum Branch is essentially the process of carrying out the wishes of the membership and acting in what is believed to be the best interests of the members. This does not appear to be a difficult objective, but it has a joker in that it is not always easy to determine the wishes of the membership.

This is particularly true in an organization such as the Branch, where there is such a wide diversity of technical interests, and hence a wide range of opinion on what we should present and publish in technical literature. During recent years, many members have contended that the majority of our papers have been too technical for the average engineer to assimilate and apply. This current of opinion has been strong; some members have considered withdrawing from the society because of the nature of the material published. Their demand has been for "practical operations papers."

On the opposite end of the scale, and perhaps equally strong, is the opinion that we should largely confine our papers to research and new methods. This point of view holds that what is re earch today will be operational practice tomorrow, and that we must carry on progressive education. In the middle is a large bloc of members who are convinced that neither extreme is right, and that a balance must be struck between the two.

As always in problems dealing with a balance of human feeling, the final answer is compromise. I believe there are two essential requirements in the problem:

1. To give all members something in their field that will be useful to them,
2. To provide an outlet for the reporting of research and new developments.

I further believe that the solution to the problem is to be found in the proper balance between these two requirements.

As an aid to finding the proper balance, a recent survey was conducted in the Branch to measure membership interest in the various technical fields with which we deal. A questionnaire listing 54 technical subjects was sent to every other member; they were asked to check the fields in which they were primarily interested and on which they would like to see more papers published. About 2,150 questionnaires were mailed, and 659 were returned, for a percentage return of 30.5 per cent. Previous surveys have indicated that the results level off at about 400 responses, and any additional returns will not affect the survey. Therefore, the sample and returns were large enough for accurate results.

The results are shown in the adjacent table. The figure for each technical subject is a percentage of the total responses, and the totals shown are then in ratio to 100.

The Branch Technology Committee used this survey as a guide in selecting papers for the program, as shown on Page 6, Section 2 of this issue, for the forthcoming Fall Meeting in Houston. The survey was very useful in this way, and the balance between membership interest and meeting pa[illegible] as follows:

Field of Technology	*Interest Ratio — to 100*	*Meeting Papers*
Rotary drilling	13.1	3
Well completion	25.5	8
Production equipment	9.4	3
Production operations	20.6	7
Production re earch	11.4	10
Gas technology	9.2	5
Miscellaneous (economics and management)	10.8	4

This program seems to meet the two essential requirements stated above. Every field of our technology has a number of papers proportionate to its strength of membership interest. The only one that is significantly out of

Continued on Page 10, Section 2

MEMBERSHIP INTEREST IN VARIOUS TECHNICAL FIELDS

ROTARY DRILLING

Mud techniques	2.6%
Mud systems	1.2
Bits	.9
Drill Collar care	.4
Drill Pipe care	.4
Casing programs	2.1
Casing cementing	2.2
Offshore	.9
Directional drilling	1.3
Land power rigs	.6
Barge power rigs	.5
Total	13.1%

WELL COMPLETIONS

Logging	3.7%
Perforating	2.2
Acidizing:	
Oil wells	2.6
Gas wells	1.8
Packers	1.7
Formation testing	2.5
Squeeze operations:	
Cementing	2.4
Plastics	2.5
Hydrafrac	2.8
Techniques for producing thin oil columns	3.3
Total	25.5%

GAS TECHNOLOGY

Separation and dehydration	1.6%
Cycling and gas producing	1.6
Gas transmission	.6
Natural gasoline processing	.7
Underground storage	1.6
Reserve evaluation	3.1
Total	9.2%

PRODUCTION

Equipment:		
Paraffin troubles	1.8%	
Salt water disposal	1.7	
Lease storage for corrosive crudes	.8	
Offshore storage	.5	
Artificial lifts:		
Gear units	.8	
Hydraulic units	.9	
Gas lift	1.5	
Sub-surface equipment	1.4	9.4%
Operations:		
Methods	1.9	
Problems	2.2	
Pressure maintenance	3.7	
Reservoir Mechanics	3.6	
Field Histories	2.6	
Secondary recovery	4.0	
Corrosion	1.6	
Technical services	1.0	20.6%
Research:		
Capillary pressure	1.7	
Core analysis	2.7	
Fluid flow	2.4	
Relative permeability	2.6	
Phase relations	2.0	11.4%
Total Production		41.4%

MISCELLANEOUS

Economics	2.8%
Refining	.1
Management	2.4
Engineering education	1.6
Exploration:	
Geology	2.4
Geophysics	1.5
Total	10.8%

The Drift of Things

. . . as followed by EDWARD H. ROBIE
Secretary AIME

Engineers' Centennial

This summer, in Chicago, the "Centennial of Engineering" will be celebrated and half a hundred engineering societies will have meetings of one kind or another in the two weeks following Labor Day. It is really the 100th anniversary of the founding of the American Society of Civil Engineers. Centennial of Engineering is merely a convenient label to put on the celebration of 100 years of engineering progress in this country since the ASCE was founded. Engineering, of course, is much older than is thus indicated — thousands of years older. But Americans have a penchant for dramatizing progress by celebrating assumed anniversaries. Four years ago a special three-cent stamp was issued on which a Brahma chicken was prominently displayed, with the legend, "1848-1948. Centennial of the American Poultry Industry." We feel reasonably sure that the first dozen eggs was sold considerably earlier than that.

Until a hundred or so years ago engineers were generally classified as either military or civil. Apparently a group of civil engineers met for the first time in Augusta, Ga., but no records were kept and the first meeting of which we have definite knowledge was at Barnum's Hotel in Baltimore, Feb. 11, 1839. Forty engineers were present and they decided to form a society. Among the aims of these engineers was "the greatest amount of useful effect at the smallest cost," which is as good a slogan for the engineer of today as it was 113 years ago. It was mentioned that the existence and prosperity of the society depended in no small degree on "the personal conduct and exertions" of the members. "Talents and respectability are preferable to numbers . . . from too easy and promiscuous admission, unavoidable, and not infrequently incurable, inconveniences perplex most societies."

The name American Society of Civil Engineers was selected. It was recommended that "architects and eminent machinists" be admitted to only associate membership. The founding committee recommended that every Member and Associate be required "to produce to the Society at least one unpublished communication in each year, or present a scientific book, map, plan, or model not already in the possession of the Society under penalty of $10." Apparently the society was too exclusive and the penalty for the unproductive member a bit too steep, ten bucks being what it was in those days, so the society died a-borning. An effort was, however, made to set up four engineering societies on a geographical basis, with one covering New England and New York; the second Pennsylvania, New Jersey, Maryland, Delaware, and Virginia; the third all the states south of Kentucky and Virginia; and lastly "Kentucky and the Northwestern States." Something along this line was accomplished when the Boston Society of Civil Engineers was founded in 1848.

Efforts to organize a national society were finally successful in 1852 when the American Society of Civil Engineers and Architects was founded. There was but one grade of membership, to which were eligible "Civil, Geological, Mining, and Mechanical Engineers, Architects, and other persons who, by profession, are interested in the advancement of science." Those educators of the present day who take a dim view of the curricula labeled "geological engineering" can thus see that geological engineers were at least given early recognition.

In 1853 the Society held eight meetings, with an average attendance of six, and in all only 14 different members came to the meetings. In 1854 only six meetings were held, and attendance was less than in 1853 so resident dues (for those within 50 miles of New York) were reduced from $10 to $5 and non-resident dues from $5 to $3. This was done to "render membership less onerous, and with the hope that by so doing new members might be induced to seek a connection with the Society . . . the labors of the members more than their money is wanted to make the Society useful."

The Society had no headquarters so it was proposed to rent a room convenient to the office of some member who might be willing to supervise it, the annual rental of the room not to exceed $250, and the cost of furnishing not more than $150.

After its meeting on March 2, 1855, the new Society was dormant for 12 long years, during which period the Civil War was fought. It came to life, with two rooms as headquarters in downtown New York, in 1867. Dues were put back up to $10 and $5, and the assets of the society were $1,592.07. The next year the words "and Architects" were deleted from the Society's name, but it remained a society for all engineers even after the mining engineers formed the AIME in 1871. In 1855 a member of the Society asked "whether any Transactions of the Society have been published or intended to be" (grammar was evidently not pure even in those days) but it was not until 1872 that the Civils published their first volume of Transactions. That was only one year before the first volume of AIME Transactions was published. A members' badge was not adopted until 1884 though the AIME had previously adopted one, and the American Society of Mechanical Engineers, founded in 1880, likewise. The Electricals did not form a separate society until 1884, and used the Civils quarters for several years. The Chemicals did not branch off on their own until 1908.

On Feb. 14, 1903, Andrew Carnegie wrote the following letter:

"Gentlemen of the American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Mining Engineers, American Institute of Electrical Engineers, and the Engineers' Club: It will give me great pleasure to give, say, one million dollars to erect a suitable Union Building for you all, as the same may be needed. With best wishes, Truly yours, Andrew Carnegie." The societies were required to purchase suitable property on which to erect the building. The final amount that Mr. Carnegie gave was $1,050,000, and the present Engineering Societies Building was dedicated on April 16 and 17, 1907. The Civils did not move in and become one of the four "Founder Societies" until about 10 years later.

We are indebted to a history of the ASCE prepared by Edward C. Thoma for most of the above information. With the present building soon to celebrate its 50th anniversary, what we engineers now need is another Andrew Carnegie. Unfortunately the political climate is not now so favorable for accumulating large fortune which may be available for such purposes as it was a half century ago. ★ ★ ★

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 408 Trinity Universal Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to the positions coded Y7073, Y7072 and Y6685 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

POSITIONS

♦ Manager of engineering, 40-50, with minimum of five years' experience as engineering head of chemical, petroleum or process equipment design. Must be experienced in product design, standardization and application of large-sized heat transfer equipment and pressure vessels. Salary, $15,000 a year. Location, New York State. Y7073.

♦ Mechanical construction engineer with five to ten years' experience on petroleum, oil and liquid piping work for large airport construction project. Salary, $11,440 a year including board and maintenance. Location, Turkey. Y7072.

♦ Instructor or assistant professor, 25-30, with a few years' practical experience in petroleum production engineering. Should be American citizen. Salary, up to $5,000 a year depending on experience. Location, West. Y6685.

♦ Petroleum technicians, who are linguists and available as translators of technical material on a part-time basis. State technical background, translating experience and desired fee. Inquiries should be addressed to Berlitz Translation Service, 630 Fifth Ave., New York 20, N. Y.

PERSONNEL

♦ Petroleum engineer-production geologist, master's degree, varied experience in Rocky Mountain, Gulf Coast, Mid-Continent and West Texas areas, age 30. Presently district engineer with major oil company. Desires responsible position. Preferable location in West Texas. Code 165.

♦ Petroleum engineer, versatile, competent, personable; seven years well-rounded field experience oil and gas drilling and production, including secondary recovery. Age 31. Presently employed in supervisory capacity. Not essential but prefer southwest location with substantial independent or operating consultant. All inquiries welcomed and acknowledged. Code 166.

♦ Reservoir engineer, 27, married, desires change to a progressive small company or a major company. Now employed by a major company. Five years' experience in production and reservoir engineering. Will consider a position in either production or reservoir engineering. Code 167. ★ ★ ★

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AIME Nominating Committee Offers Slate of Ten Nominees for '53 Offices

John R. Suman, Chairman of the Nominating Committee, has announced nominations for President-elect, Vice-Presidents, and Directors for 1953. As provided in Art. IX, Sec. 2, of the bylaws, 25 members or associate members may sign and transmit to the Secretary's office prior to Sept. 1 "any complete or partial ticket of nominees," should they wish other candidates to be considered.

In such instance, a letter ballot will be forwarded to all members in good standing in the United States, Canada, and Mexico, tabulating both the official ballot and any supplementary nominations. If no supplementary nominations are thus received, no letter ballot will be printed, and nominees on the official ballot shall be declared duly elected at the meeting of the Board of Directors or the Executive Committee in November.

FOR PRESIDENT

Andrew Fletcher, president of St. Joseph Lead Co., was born in 1895 in New York City. Educated at Hill School and the Sheffield Scientific School, he received a Ph.B. in mechanical engineering from Yale University. In 1949 the University of Missouri conferred upon him an honorary degree of Doctor of Engineering. In addition to being president of St. Joseph Lead Co., he is also president of Mine La Motte Corp. and Bonne Terre Farming and Cattle Co. He is also vice-president of Missouri-Illinois Railroad Co. and director of the American-Hawaiian Steamship Co. He has been on the Board of Directors of AIME for many years and Treasurer since 1944.

FOR PRESIDENT-ELECT

Leo F. Reinartz has been nominated for the Presidency of AIME in 1954. Reinartz is now vice-president, special operating development, Armco Steel Corp. Born in East Liverpool, Ohio, he graduated from the Carnegie Institute of Technology as metallurgical engineer. He joined Armco in 1909 as a chemist and then became open hearth foreman; assistant superintendent, open hearth dept.; superintendent, open hearth dept.; assistant general superintendent; works manager, East works; manager, Middletown div.; and assistant vice-president, respectively. Reinartz has been active in many technical societies and delivered papers before several. He also has been the recipient of the Alumni Award from Carnegie and holds life honorary membership in the AIME National Open Hearth Conference. One of the organizers of the Open Hearth Conference, Reinartz was Chairman, Executive Committee (1927 to 1946) and is presently chairman of the Finance Committee. In October, 1951, he was an American Conferee at the First World Metallurgical Congress held in Detroit. An AIME member since 1925, Reinartz has been active on numerous committees of the Institute.

FOR VICE-PRESIDENTS

Augustus B. Kinzel has been nominated as a Vice-President and Director of AIME. Kinzel graduated from Columbia University in 1919 (A.B.); from Massachusetts Institute of Technology in 1921 (B.S. in general engineering); and in 1922 received a D. Met.Ing. from the University of Nancy where he also received the degree of Doctor of Science. Kinzel has been associated with various metallurgical units of Union Carbide and Carbon Corp. since 1926 and was chief metallurgist of its laboratories from 1931 until he assumed the presidency of the research laboratories in 1947. He is a member of various government committees and is widely known as a lecturer. He was the AIME Howe Memorial lecturer for 1952.

Lloyd E. Elkins, production research director, Stanolind Oil and Gas Co., has been nominated as a Vice-President and Director, AIME. Born at Golden, Colo., in 1912, he received his degree in petroleum production engineering from the Colorado School of Mines. Following graduation he was employed by the Stanolind Oil and Gas Co. at Wink, Tex., and has risen steadily during his years with the company. In 1948 Elkins was selected to attend the advanced management program at the Harvard Graduate School of Business Administration. He has been active in the Petroleum Branch of AIME as Chairman, Mid-Continent Section (1945); Vice-Chairman, Petroleum Division (1947); and Chairman, Petroleum Branch (1949). In addition to being an AIME member, Elkins belongs to the API, Tulsa Geological Society, Oklahoma Society of Professional Engineers, Engineers' Club of Tulsa (president, 1950 to 1951), Petroleum Club of Tulsa, and American Association of Petroleum Geologists.

FOR DIRECTORS

Philip D. Wilson has been nominated Director of AIME for a three-year term beginning February, 1953. Wilson has previously served as Chairman of the New York Section (1950) and is also a Council Delegate, New York Section. Wilson graduated from Princeton University in 1909 (B.S.) and Columbia University School of Mines in 1911 (E.M.). He was employed by various mining companies and in 1914 joined the Calumet and Arizona Mining Co. as chief geologist. He joined the American Metal Co., Ltd., and was located in South America, South Africa, Europe, Cuba, Mexico, and New York City. He was also general manager of the subsidiaries in Chile and South Africa. From 1934 to 1942 Wilson was vice-president of Pardners Mines Corp. During the second world war he was a member of several government boards and in 1946 joined Lehman Bros. and Lehman Mining Corp. Presently he is consulting mining engineer for this firm. Wilson is a member of various technical societies, and was also elected to several honorary societies.

Edwin Letts Oliver, president of Oliver United Filters, Inc., has been nominated to serve as an AIME Director from 1953 to 1956. A Life Member of AIME and member of the Legion of Honor (class of 1902), Oliver was born in San Francisco. He graduated from the University of California in 1900 and following graduation spent three years working in mines both in America and Mexico. In 1903 he became surveyor and later metallurgist on the staff of the North Star Mines Co., Grass Valley, Calif. He patented a continuous automatic filter for use in the cyanide process and in 1910 opened an office under the name of Oliver Continuous Filter Co. In 1928 Oliver United Filters, Inc., was formed by consolidation with United Filters Corp. Oliver was Chairman of the James Douglas Gold Medal Committee in 1944. In 1945 he received the honorary degree of Doctor of Laws from the University of California. A member of professional societies both here and abroad, he holds numerous patents in connection with filtration equipment.

Hjalmar W. Johnson, vice-president, Inland Steel Co., has been nominated as a Director of AIME for three years. He was a Director from 1949 to 1951 and served as Chairman of the Chicago

Section in 1942. Born at Joliet, Ill., Johnson is a graduate of the University of Illinois (B.S.). He was employed by the Illinois Steel Co. at Joliet and later was blast furnace foreman for U. S. Steel Corp. In 1929 he joined Inland as assistant superintendent of blast furnaces. In 1930 he was promoted to superintendent of blast furnaces, and in 1942 became assistant general superintendent. Johnson was appointed staff assistant to the president in 1946 and three years later was appointed to his present position. Johnson received the J. E. Johnson, Jr. (AIME) award in 1933 and the American Iron and Steel Institute Medal in 1941.

Elmer Henry Isern has been nominated as an AIME Director for a term from 1953 to 1956. He is a former member of the Milling Methods Committee, 1950 member of the James Douglas Gold Medal Committee, and is present Chairman, Richards Award Committee. Isern was born in Ellinwood, Kan., June 4, 1899, and graduated from Kansas University in 1922. After graduation Isern was a research engineer for the Anaconda Mining Co. He was later promoted to mill superintendent and in 1926 joined the Commerce Mining and Royalty Co. He joined the Eagle-Picher Mining and Smelting Co. in 1939 as superintendent of milling. In 1944 Isern was appointed vice-president and director. He was later named president of Eagle-Picher Mining and Smelting Co. and director, the Eagle-Picher Co. He is presently vice-president and director, the Eagle-Picher Co. and general manager, mining and smelting division, the Eagle-Picher Co. Isern is an officer and member of various professional societies.

Philip Kraft, currently Vice-President of AIME and Vice-Chairman of its Executive Committee, has been again nominated Director to serve from 1953 to 1956. He was born in New York City in 1890, received his BS degree from Columbia College (1910), EM degree from Columbia School of Mines (1912) and went on to the Royal School of Mines, Berlin, for his Doctor of Engineering degree (1914). Kraft spent three years in Canada as a geologist and mining engineer, and from 1917 to 1925 was engaged in war activities, mining examinations, and consulting work. He is director in charge of oil activities of Newmont Mining Co., and president of Newmont Oil Co. In addition, he is a director of Cyprus Mines Corp., and a number of other companies engaged in the mining, oil, and gas industries. At one time or another, Kraft has served on most of the important AIME committees, not the least of which has been the committee to administer endowment fund X.

Gail Francis Moulton, presently a Director of AIME, has been renominated for a three-year term beginning 1953. Born in Chicago in 1898, he graduated from the University of Chicago in 1920. Moulton has had extensive experience in the petroleum industry, served as assistant professor at University of South Dakota, and headed the petroleum section of the Illinois State Geological Survey. He was later employed by United Gas Co., Electric Bond and Share Co., and Ralph E. Davis, Inc. Late in 1951, he joined Rockefeller Brothers, Inc., as a consultant, with offices at 30 Rockefeller Plaza, New York City. A former Vice-Chairman of the Petroleum Branch, Moulton is a prolific writer in his field, and has served on many AIME committees. ★

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"Here is reproduction of drift indicator disc, showing both recordings 4½° off vertical."
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TENTATIVE PROGRAM

for

Papers and Activities

PETROLEUM BRANCH, AIME, FALL MEETING

Rice Hotel, Houston, Texas, October 1, 2, 3, 1952

(All papers shown are subject to change or withdrawal.)

Tuesday, September 30

5:00 p.m. - 9:00 p.m. — Advance Registration Mezzanine

8:00 p.m. - 10:00 p.m. — Petroleum Section and Chapter Conference — Jade Room

Wednesday, October 1

8:00 a.m. to 5:00 p.m. — Registration and Exhibits Mezzanine

9:00 a.m. to 11:15 a.m. — Technical Session — Production Equipment — Ballroom

200-G: *The Gas Lift Principle as Applied in Two New Well Pumping Systems*, by E. D. McMURRAY, Garrett Oil Tools, Inc.

231-G: *Permanent Type Well Completions*, by T. A. HUBER and G. H. TAUSCH, Humble Oil and Refining Co.

202-G: *High Pressure Wellhead Lubricator*, by HOWARD E. McKINNEY, Shell Oil Co.

9:00 a.m. to 11:15 a.m. — Technical Session — Well Completion South American Room

203-G: *The Establishment of Skin Effect and Its Impediment to Fluid Flow into a Well Bore*, by WILLIAM HURST, Petroleum Consultants, and H. RAINBOW and A. F. van EVERDINGEN, Shell Oil Co.

204-G: *Improved Technique Developed for Acidizing Gas Producing and Injection Wells*, by JENS NIELSEN and W. H. JUSTICE, La Gloria Corp.

205-G: *Rock Fracturing as Affected by Fluid Properties*, by P. P. SCOTT, JR., W. G. BEARDEN and ARTHUR LUBINSKI, Stanolind Oil and Gas Co.

12:00 m. to 2:00 p.m. — Welcoming Luncheon for Ladies and Gentlemen — Ballroom

2:30 p.m. to 5:00 p.m. — General Interest Session Ballroom

The Model Oilfield as a Means of Explaining Oil Production and Reservoir Behavior to Unitization Prospects, by JACK TARNER, Phillips Petroleum Co.

How the Petroleum Branch of AIME Can Serve Engineers in the Petroleum Industry, by M. L. HAIDER, Standard Oil Co. (N.J.), and President, AIME, for 1952.

The Pressure Performance of Five Wells Completed in a Common Aquifer, by W. D. MOORE and L. G. TRUBY, Humble Oil and Refining Co.

7:00 p.m. to 10:00 p.m. — Buffet Supper (Tentative) For Ladies and Gentlemen — Shamrock Hotel

Thursday, October 2

8:30 a.m. to 11:15 a.m.—Technical Session—Drilling Technology Ballroom

207-G: *An Inhibited Mud for Drilling Water-Sensitive Pay Zones*, by G. E. HENDRICKSON, Cities Service Oil Co.

208-G: *Fluid Mechanics of an Oil Well Drilling String*, by WILLIAM M. KOCH, Reed Roller Bit Co.

209-G: *Use of Charcoal in Cement to Combat Effects of Contamination by Drilling Muds*, by B. E. MORGAN and G. K. DUMBAULD, Humble Oil and Refining Co.

9:00 a.m. to 12:00 m. — Technical Session — Production Operations - Water Flooding — South American Room

211-G: *Studies of the Effect of Mobility Ratio on Sweep-Out Pattern*, by R. L. SLOBOD and B. H. CAUDLE, The Atlantic Refining Co.

212-G: *Water Flooding on the Wiederkehr Lease*, by D. M. COLLINGWOOD and R. J. BETHANCOURT, Sun Oil Co.

213-G: *Properties of Linear Waterfloods*, by L. A. RAPOPORT and others, The Carter Oil Co.

1:30 p.m. to 5:00 p.m. — Open Meeting, Branch Executive Committee — Jade Room

2:00 p.m. to 5:00 p.m. — Technical Session — Well Completion - Logging — Ballroom

215-G: *Source of the Electric Potential Measured in Wells*, by W. M. McCardell, W. O. Winsauer and M. Williams, Humble Oil and Refining Co.

216-G: *Resistivity Measurements on Small Core Samples by the Two-Electrode and Four-Electrode Methods*, by Carl F. Rust (and possibly a co-author), Magnolia Petroleum Co.

192-G: *Neutron Derived Porosity — Influence of Bore Hole Diameter*, by C. B. Scotty and E. F. Egan, The Texas Co.

217-G: *The Microlaterolog*, by H. G. Doll, Schlumberger Well Surveying Corp.

1:30 p.m. to 5:00 p.m. — Technical Session — Gas Technology South American Room

218-G: *A Laboratory Investigation of Oil Displacement from Porous Media by a Liquefied Petroleum Gas*, by J. H. Henderson, Gulf Research and Development Co., and N. D. Grove, H. J. Ledbetter and J. D. Griffiths, Gulf Oil Corp.

193-G: *Low Temperature Phase and Volumetric Behavior of Natural Gases*, by T. L. Gore, P. C. Davis and F. Kurata, University of Kansas.

233-G: *Pressure Gradients in Natural Gas Reservoirs*, by David Cornell and Donald L. Katz.

190-G: *Desorption of Hydrocarbons from an Unconsolidated Sand*, by Charles W. Oxford and R. L. Huntington, School of Chemical Engineering, University of Oklahoma.

*Paper for Discussion Only

219-G: *Equilibrium Constants for a Gas-Condensate System*, by A. E. Hoffman, J. S. Crump and C. R. Hocott, Humble Oil and Refining Co.

8:00 p.m. to 1:00 a.m. — Petroleum Branch Banquet and Dance Ballroom

Friday, October 3

9:00 a.m. to 12:00 m. — Economics and Management Session South American Room

A paper on the impact of the Williston Basin on the supply and demand relationship throughout the Rocky Mountain and Alberta crude producing areas, by John Winger, Chase National Bank.

A possible paper on the Middle East situation, by Walter Levy, Petroleum Consultant.

Two other papers on economics and management.

8:30 a.m. to 12:00 m. — Technical Session—Production Research Ballroom

194-G: *Variables Affecting Restored-State Determination of In Place Oil*, by Henry Lewelling and W. E. Grubb, The Atlantic Refining Co.

220-G: *Determination of Limestone Performance Characteristics by Model Flow Tests*, by C. R. Stewart, F. F. Craig and R. A. Morse, Stanolind Oil and Gas Co.

221-G: *Calculation of Unsteady-State Gas Flow Through Porous Media*, by G. H. Bruce, D. W. Peaceman, H. H. Rachford, Jr., and J. D. Rice, Humble Oil and Refining Co.

222-G: *Surface Area Measurements on Sedimentary Rocks*, by C. S. Brooks and W. R. Purcell, Shell Oil Co.

223-G: *Formation Factors of Unconsolidated Porous Media: Influence of Particle Shape and Effect of Cementation*, by M. R. J. Wyllie and A. R. Gregory, Gulf Research and Development Co.

1:30 p.m. to 5:00 p.m. — Technical Session—Production Research Ballroom

*206-G: *Flow into Oil Wells Through Perforations*, by H. I. Meyer, United Gas Corp.

225-G: *Relative Permeability Curve Calculation from Pore Size Distribution Data*, by M. T. Burdine (and possibly a co-author), Magnolia Petroleum Co.

227-G: *Theoretically Indicated Methods of Wetting Liquid Relative Permeability Measurement*, by William H. Hartwig, University of Texas.

232-G: *Bubble Formation in Supersaturated Hydrocarbon Mixtures*, by Harvey T. Kennedy, Texas A&M College, and Charles R. Olson, Ohio Oil Co.

1:30 p.m. to 4:00 p.m. — Technical Session — Production Operations — South American Room

228-G: *Estimation of Permeability in the Spraberry Formation as Determined by Use of Build-Up Curve Analysis*, by A. B. Dyes and O. C. Johnston, The Atlantic Refining Co.

229-G: *Application of the Material Balance Equation to a Partial Water Drive Reservoir*, by J. J. McMahon, E. H. Timmerman and A. F. van Everdingen, Shell Oil Co.

230-G: *Water Input Profile Determinations on Injection Wells in Secondary Recovery Fields*, by Bliss Adamson, Halliburton Oil Well Cementing Co.

*Paper for Discussion Only

187-G: *A Method for Predicting the Tendency of Oil Field Waters to Deposit Calcium Carbonate*, by Henry A. Stiff and Lawrence E. Davis, The Atlantic Refining Co.

1:00 p.m. to 6:00 p.m. — Field Trip to Texas Gulf Sulphur Co., Newgulf

*The Branch Technology Committee has adopted a new plan this year of including a few high quality technical papers for discussion *only* at the Fall Meetings. The plan is simply for these papers to be scheduled in a technical session for discussion without oral presentation. Preprints of the papers will be distributed at the meetings, and the authors will be available at the sessions to reply to questions and discussion. The Committee feels that this plan will permit the inclusion of some papers on the program that might not otherwise be included.

$750 Scholarship Set Up In Petroleum Engineering

An offer transmitted to the Institute by J. I. Laudermilk, of the Socony-Vacuum Oil Co., for the establishment of a scholarship in petroleum engineering for the academic year 1952-53 was accepted at the May 21 meeting of the Executive and Finance Committees. The amount of the grant is $750. The Directors voted that it be administered by the Mineral Industry Education Division of the AIME. This is the first scholarship to be given to the Institute for administration in recent years. Several scholarships are, however, granted by the Woman's Auxiliary, AIME, from their own funds.

The scholarship will be known as the AIME - Socony-Vacuum Scholarship in Petroleum Engineering. It will be granted to a student who expects to complete his academic work during the period of the award, so is not open to those who expect to take graduate work. ★ ★ ★

Statistics Vol. Prices Set

Prices for back volumes of *Statistics of Oil and Gas Development and Production* have been established as follows: The separate annual volumes covering data through 1950 will be sold for $6 less 30 per cent to AIME members and public libraries, and less 20 per cent to booksellers. The current volume, covering data for 1951, to be issued later this year, will be priced at $5 for AIME members and $10 for nonmembers. ★ ★ ★

AIME Meeting to be Held With Engineer Centennial

Plans for the fall meeting of the AIME, to be held in conjunction with the Centennial of Engineering — marking the 100th anniversary of the Society of Civil Engineers — indicate that the Chicago gathering will be one of the most significant in Institute history. Headquarters for the six divisions represented will be the Palmer House.

Twenty technical sessions will be held from September 3 to 6, with papers of industry-wide impact to be presented. The papers will promote the theme of the celebration — a century of engineering progress.

The Chicago Section will be host at a dinner Friday evening, preceded by an AIME business meeting. An all-Institute dinner dance is listed for Saturday night. AIME Board of Directors convene Sunday, Sept. 7, at 2 p.m.

Thus far, 44 scientific societies have signified that they will participate in the 10-day celebration, scheduled to last until Sept. 13. At least 15 foreign countries will participate officially. The Centennial celebration is expected to be the greatest convocation of engineers on record. ★ ★ ★

Dues Referendum Mailing Being Made to Members

A referendum on dues is currently being conducted by the Institute. A statement of the Board's position in the matter and a ballot for voting was mailed to all paid-up AIME members in the United States, Canada, and Mexico on June 16, returnable to the Secretary's office not later than July 15. All members who receive a ballot are urged to vote for a continuance of the present scale of dues, so that present Institute services can be fully maintained and, it is hoped, expanded in the future as income permits. ★ ★ ★

New Ruling for Juniors Serving in Armed Forces

Revision of the former directive regarding handling of applications for Junior Membership in the Institute, from those who have served in the armed forces, was voted at the meeting of the Executive and Finance Committees May 21. The new ruling, effective immediately, is as follows:

"Subject to approval of the Admissions Committee in individual cases, all veterans who have served in the armed forces of the United States or friendly countries who apply for Junior Membership will be allowed a credit of one year on the entrance age limit of 30 years for each year of military service up to three years. Any portion of total continuous military service in excess of six months shall constitute a full year credit; similarly, any portion less than six months shall not be considered. Applicants attaining Junior Membership under this regulation shall be allowed a similar credit beyond the 33-year age limit for changing status to Associate Member or Member." ★ ★ ★

Proposed for Membership, Petroleum Branch

Total AIME membership on May 31, 1952, was 17,772; in addition 2,413 Student Associates were enrolled.

ADMISSIONS COMMITTEE

T. D. Jones, Chairman; Thomas G. Moore, Vice-Chairman; Harold S. Bell, F. W. Hanson, R. H. Chadwick, T. W. Nelson, J. H. Scaff, John T. Sherman, A. C. Brinker, Ivan Given, C. A. R. Lambly, G. P. Lutjen, E. A. Prentis, and C. Leslie Rice, Jr.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

CALIFORNIA

Bakersfield — Norton, Craig R. (R,C/S-S-J).
El Cajon — Kranyak, Atilla D. (J).
Santa Maria — Plasch, William (M).

COLORADO

Colorado Springs — Magruder, James A. (C/S-A-M).

KANSAS

Eureka — Clark, Ward McG. (J); Collins, Joseph P. (R,C/S-S-J).
Madison — Adamson, Emmet G. (J).
Thrall — Krehbiel, Dennis L. (RC/S-S-J).

LOUISIANA

New Orleans — Acomb, Allen D. (C/S-A-M).

MISSISSIPPI

Brookhaven — McWhorter, Clayton C. (A).

NEW YORK

Forest Hills — Greenstein, Robert I. (C/S-S-J).

NORTH CAROLINA

Concord — Robbins, Raymond K. (R,C/S-S-J).

NORTH DAKOTA

Bismarck — Jenkins, Ralph E. (J).

OKLAHOMA

Oklahoma City — Campbell, John M. (M).
Tulsa — Caylor, Garth W. (R,C/S-J-M); Marrs, Doyle G. (C/S-S-J); Mesill, Robert E. (J).

PENNSYLVANIA

Ivyland — Slezak, John M. (C/S-S-J).
Oakdale — Fiedorek, Eugene C. (C/S-S-J).
Philadelphia — Swartz, Henry J. (C/S-S-J).

TEXAS

Abilene — Coppinger, John E. (R,C/S-S-J); McDermott, William E. (M).
Athens — Clevenger, Paul R. (R,C/S-S-J).
Bellaire — Tullos, Aubrey F. (M).
Breckenridge — Paine, Charles B. (J).
Columbus — Etheridge, Kirby F., Sr. (M).
Corpus Christi — Griffin, Phil H., III (J).
Crane — Demmler, Eugene (M).
Dallas — Burdine, Nathan T. (M); Neighbors, Glen R. (R,C/S-S-M).
Houston — Cooke, William F. (M); Edwards, Lyman M. (M); Gustavsen, Jack G. (A); Hole, Arnold (M); Miller, John Cummins, Jr. (R, C/S-S-J); Tausch, Gilbert H. (J).
Lubbock — Wilson, Merrill B. (R,C/S-S-J).
San Antonio — Calvert, Cecil H. (R,C-S-S-J).
Wichita Falls — Jones, Dan M. (C/S-S-J).

HOLLAND

The Hague — Schepers, Lykle (M).

CANADA

Mossleigh, Alberta — Gateman, John C. (C/S-S-J).

INDONESIA

Djakarta — Halkers, Arend A. (M).
Sumatra — Duggan, George L. (A); Smith, Paul C., Jr. (J).

IRAQ

Kirkuk — Arthur, Kenneth B. (J); Drummond, William N. (J); Pearse, Thomas C. (M); Ritchie, George (J).

MEXICO

Mexico City — Aldredge, Robert F. (M).

PERSIAN GULF

Qatar — Gardiner, Michael A. (J); Grimsey, Alfred H. (M); Wood, David P. (A).

VENEZUELA

Caracas — Lehmann, Charles F. (J).

Personals

A. Rodger Denison has been awarded the honorary degree of Doctor of Science by the South Dakota School of Mines and Technology. The citation reads: " . . . for his continuous participation in the activities of national associations, societies, and institutes devoted to geology and petroleum exploration; for his untiring efforts in the education and placement of students of geology and engineering; for his enduring contributions through his publications to knowledge in those fields; and especially for his outstanding accomplishments in petroleum exploration."

+

Howard H. Hinson, assistant manager, production dept., Continental Oil Co., Houston, is now regional general manager at Fort Worth.

+

John Austin Jones is now employed as a petroleum engineer by the Panhandle Eastern Pipe Line Co., Liberal, Kan.

+

Stewart H. Folk is now geologist with the Texas Gulf Sulphur Co., Houston, Tex. He had been located in Mexico, D. F., for Petroleos Mexicanos.

+

W. Irving Harris, Jr., has accepted a position with the Houston Oil Co. of Texas, Silsbee, Tex.

+

Herbert D. Christner, Continental Oil Co., has been made division petroleum engineer, production department, Oklahoma City, Okla.

+

Normand E. Slick has resigned from the Tide Water Associated Oil Co., Ventura, Calif., and is now petroleum engineer for the U. S. Navy Naval Petroleum Reserve No. 1 at Tupman, Calif.

+

Byron L. Plumley is now senior petroleum engineer, production, for the Sinclair Oil and Gas Co., Ardmore, Okla.

+

Thomas B. Lowary has joined the Vinson Supply Co., Oklahoma City.

Mahlon F. Manville is no longer associated with the Sinclair Oil and Gas Co. He has joined the Johnston Testers, Inc., Houston, Tex.

+

Charles Edward Morgenthaler is a junior petroleum engineer with the Carter Oil Co., Tulsa.

+

Peter G. Burnett, Stanolind Oil and Gas Co., has been transferred from Longview, Texas, to Tulsa.

+

M. McGehee Brantly is now with Brantly-See, Inc., Midland, Tex.

+

Frederick J. Bucher has accepted a position with the Colorado Interstate Gas Co., Colorado Springs, Colo.

+

R. P. Kirkpatrick, Byron Jackson Co., has been transferred to BJ Service, Inc., as sales engineer.

+

John D. O'Bryan has been transferred from the Beeville production office to the reservoir section of the southwest Texas district office, Stanolind Oil and Gas Co., Corpus Christi.

+

E. H. Koepf, formerly with the Atlantic Refining Co., is now vice-president and general manager for the Texas City Chemicals, Inc., Texas City.

+

Edward L. Winterbauer is now with the Magnolia Petroleum Co., Luling, Tex.

+

Richard E. Wainerdi has accepted a position with the Shell Oil Co., Houston.

+

Bradford J. Sinex, Amerada Petroleum Corp., is now located in Williston, N. D. He has been at Monument, N. Mex.

+

Travis Toland is now an engineer trainee with the Sun Oil Co., Breckenridge, Tex.

+

Wesley R. Lund, exploitation engineer with the Shell Oil Co., has been transferred to New York from Houston.

+

Robert Lee Lindauer, Jr., is now associated with the Humble Oil and Refining Co., Houston.

Jean A. Bodin has been transferred from Houston to Fort Worth by the Schlumberger Well Surveying Corp. He is now northwest Texas area manager.

+

L. A. Allaud, formerly located at El Tigre, Venezuela, for the Schlumberger Well Surveying Corp., is now at Fort Worth as assistant area manager, northwest Texas area.

+

Thomas B. Garber has been transferred to the engineering staff of the Standard Oil Co. of Texas, Houston.

+

I. T. Chapman has accepted the position of assistant to the division manager, International Petroleum Co., Talara, Peru. He had been associated with the Tropical Oil Co., El Centro, Colombia.

+

Robert M. Brackbill, Shell Oil Co., Calgary, Alberta, is now located in Houston.

+

George W. Pullin, Jr., has joined J. R. Butler & Co., Houston.

+

Lester J. Hartzell has been made chief chemist, metallurgist and research engineer for the Pioche Manganese Co., Henderson, Nev. He had been research engineer for the Combined Metals Reduction Co., Salt Lake City, parent company of Pioche.

+

Paul B. Leavenworth is no longer associated with the Gulf Oil Corp.

+

Marshall Stirling, formerly sales manager of the petroleum division of Dowell Incorporated in Fort Worth has moved to Tulsa, Okla., as general sales manager for that company. He was previously located in Tulsa as sales manager of the petroleum division before moving to Fort Worth in late 1950 to head an expansion program in that area. Before joining Dowell, he was sales manager of the Gas Lift Corp. in Houston.

Geologic Principles

Continued from Page 23, Section 1

primary purpose of proving or disproving geologists' guesses rather than for the purpose of adding a few thousand barrels to the reserve of a proven field. All wildcats should be thoroughly tested for production. Many pools, now proven productive in the Williston Basin, were by-passed by early wildcatters because they failed to run enough formation tests.

In California, exploration effort should concentrate on the basins that have not yet been proven to be oil provinces. These basins, which are as numerous as the productive basins include Imperial Valley, Ridge Route Basin, Antelope Valley, Eureka Basin, and Sacramento Basin. The Sacramento Basin produces gas, but oil has never been found there. Other of these basins have been drilled but not sufficiently to prove or disprove their potentiality as oil provinces. ★ ★ ★

Petroleum Branch Affairs

Continued from Page 1, Section 2

proportion is production research. It has to be somewhat out of its strict proportion if we are to serve as a forum for the reporting of research, and I believe we must render that service if we are to thrive as a professional society.

Members are cordially invited to write and express their reactions on this survey, on the Fall Meeting program, and on our technical material in general. ★ ★ ★

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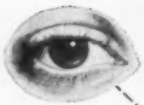
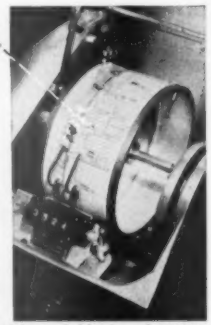


With Geolograph, you actually watch the drilling change as the bit bites into contrasting strata — foot by foot! You'll find that this subsurface control, while drilling, results in a higher percentage of successful drill stem tests; fewer and more correctly placed cores; accurate determination of net pay thickness and elimination of many depth corrections!



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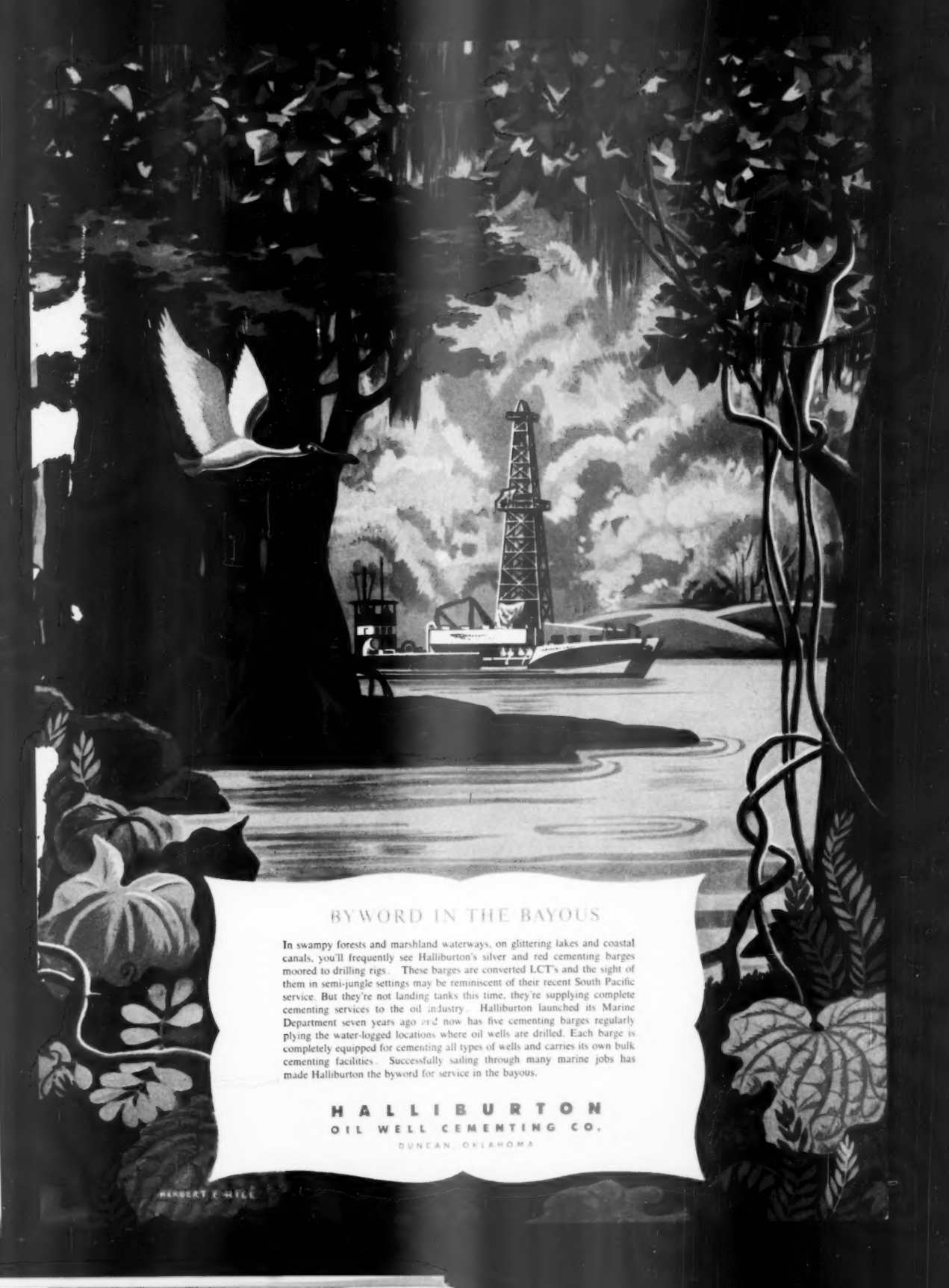

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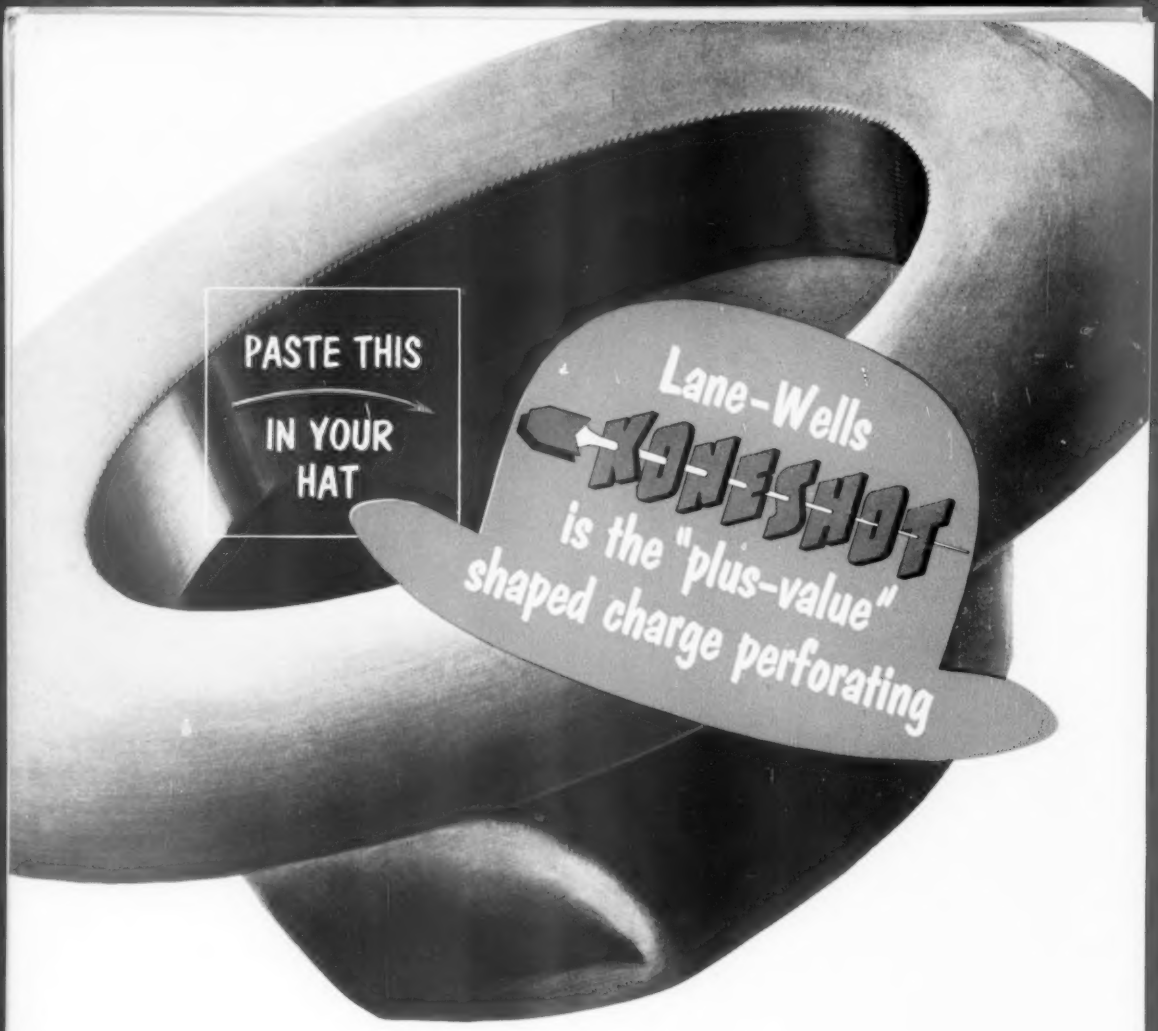
HERBERT E. HILL



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—**accurate depth measurements** that put the shots exactly where you want them; **up-to-the-minute equipment** that's fitted to the needs of the job; **experience** that has found the answers to every possible difficulty and problem; **service facilities** that bring the right tools to your rig, on time, with crews who know your local conditions; **safety procedures** that give maximum protection to property and personnel.

That's what the records show—just ask the operators who have used Lane-Wells.

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